METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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Subscription Rates throughout the World - - 24/- per annum, Post free

Published monthly by THE KENNEDY PRESS, LIMITED.

REGISTERED OFFICE: 31, King Street West, Manchester, 3.
Telephone: BLA 7086-7 *Telegrams:* "Kenpred," Manchester.

LONDON OFFICE: Bedford Street, W.C. 2.
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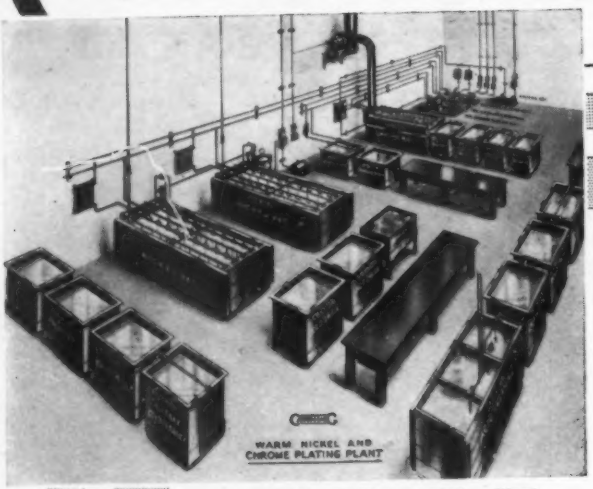

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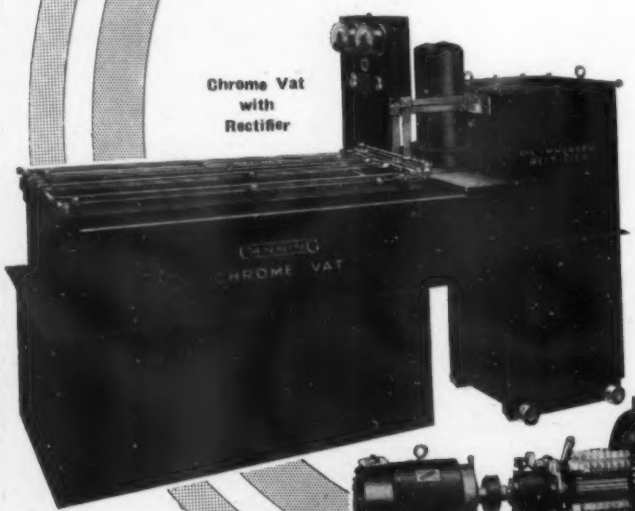

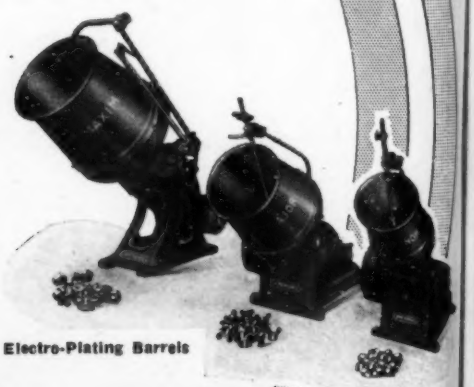

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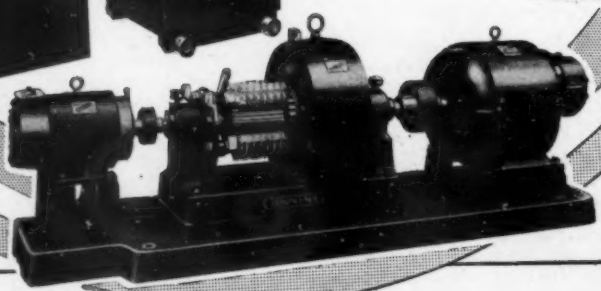

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

AUGUST, 1945 VOL. XXXII. No. 190

PEACE !

PEACE, so long fought and prayed for, has come to a tortured world rather unexpectedly and many people are still stunned by the glad news. In our first issue following the opening of hostilities, nearly six years ago, we asserted that, in declaring war upon Germany, Britain and her Empire were not seeking to win the spoils of war, but rather to defend moral values—liberty, good faith between men and nations, justice to strong and weak alike, the pledged word, and the common decencies of what we regard as essential in civilised countries. We felt that these values should not be allowed to perish. It was generally recognised at that time that the possibilities of compromise and appeasement had been exhausted and no honourable alternative remained but for Britain to take up arms in defence of these moral values.

As was partially anticipated, the conflict spread until it engulfed almost the whole world. Following the collapse of France, Britain and her Empire carried on the fight alone for a time and was subsequently joined by the Soviet Republic and by the United States, while Germany was supported by Italy and by Japan. It is probable, however, that the prelude to this great world catastrophy occurred fourteen years ago when Japan sent her armies into Manchuria, which shook the foundations of world peace and put ideas into the minds of dictators in other countries. First Mussolini, then Hitler, followed the lead, the policy of grab could not be appeased, only one answer could be given and France and Britain took the initiative. Although few in this country failed to realise the tremendous possibilities of such a war, the cause of hostilities was viewed by the British with calmness and untroubled conscience.

During the early years of the war the forces of domination went on from success to success, spreading fear, misery and death in their path, until almost the whole of Europe and a large part of Asia was overrun and conquered peoples trampled on by the enemy. Gradually, however, the democratic nations built up their forces, equipment and armour, on land, sea and in the air, and, by a series of magnificently executed counter strokes, finally brought first Italy and then Germany to their knees. And now Japan, the real instigator of the war, sees no alternative to unconditional surrender and has accepted the Potsdam conditions.

The news of Japan's collapse came as a grand finale to a week of surprises, commencing with the news of the discovery and use of the atomic bomb and including the Soviet Union's declaration of war on Japan. It is difficult to say which of these two surprises has had the most effect in hastening Japan's decision, probably their cumulative effect has brought about the desired result. It is significant, however, that the news practically blotted out political controversies and all other topics of interest to the man in the street.

None can grudge the feeling of exultation that peace has been restored to a stricken world ; even the conquered nations must feel thankful that the conflict is over and that efforts can be made to build the new world so many seek. It should be realised that the fundamental moral values for which we entered the struggle are still to be won. Millions of people have been sacrificed or deprived of all that makes life worth while to satisfy the lust for power. That the lust and greed of aggressive nations has been frustrated is an accomplishment of no mean order will be appreciated, but this is not a time for complacency ; the major work lies ahead, upon which the future of this country and of mankind in general must rest.

The discovery and development of atomic power has made the development of understanding and friendly relations between the nations more essential to-day than ever. The need for a world order is now more acute and some security system must be devised in which every nation can have absolute trust. Certainly we should guard against the precarious peace of tyranny in which weaker nations, afraid to protest, suffer and endure that the stronger nations only may remain secure and free.

But the ending of the Japanese war raises another factor which to many will be regarded as of more immediate importance to Britain. It is probable that the cessation of hostilities will bring about an early termination of the lease-lend shipments to this country and the question arises : how is Britain to cover its imports during the next few years in the absence of aid from the United States ? It must be remembered that the war has placed us heavily in debt and both exports and services must be greatly increased even if we are to approach the living conditions experienced in this country before the war. To achieve the conditions, for which our people ardently hope, demands that reconversion and reconstruction plans be put into operation with the minimum of delay and, just as understanding and friendly relations must be developed between nations, there is a pressing need for understanding and friendly relations between employers and employees to provide a basis upon which can be built Britain's prosperity. So much has been accomplished at the San Francisco Conference that a meeting of representatives of British employers and employees, possessing the will to reach a workable basis, would find a solution childs play by comparison. Whether or not efforts are made to end the disastrous strikes that cripple all progressive endeavour, we must resolve to make every effort to restore and indeed increase Britain's industrial and commercial activities to a high level.

With this thought in mind her basic industries must put their plans into operation without delay. In this respect it is noteworthy that in at least one vital industry, the iron and steel industry, plans are well ahead. According to Sir John Duncannon, the Commercial and Technical Director of the reconstituted British Iron and Steel Federation, a big modernisation and reconstruction programme is under consideration. A considerable part of the plan has been approved and work on some of it has already commenced. It is understood that the total cost will exceed £120 million and the programme will be carried through as quickly as possible. Plans are being studied for the construction of new coke ovens to produce 2½ million tons of coke, new steel works, nineteen new blast furnaces, new melting shops, replacement and reconstruction of rolling mills and a new continuous hot strip mill, together with equipment for auxillary processes. In addition, a further ten blast furnaces are contemplated to replace existing furnaces as these go out.

Given adequate building labour and reasonable priority on materials, the bulk of this work is expected to be completed within five years. By that time, modernisation of plant throughout Britain will have been achieved. Apart from increased efficiency, which is the main goal of the Federation, an important result of this reconstruction will be that the capacity for total steel ingot production in Britain will be increased by approximately 20 per cent. Progress on the modernisation plan will, of necessity, be slow at first, due to the over-riding priority being given to building labour for house construction, but work has already commenced on the rebuilding of four blast furnaces and replacement of coke ovens in Scotland and on the north-east coast. In the midlands, an expansion of open hearth capacity is now under way and the construction of new plant for the production of the latest type of hot rolled sections for window casements, for the housing programme, has begun at Darlington, with new sectional mills for the rolling of light sections for the construction of buildings. New reversing slabbing mills, cogging mills and wide sheet cold-reduction mills to supply sheets required by motor car manufacturers, unloading and ore handling plants to enable larger iron ore ships to be used in the transport of foreign ores, gas holders and pipe lines so that blast furnace gas can be re-used for industrial purposes, and extensions to the heavy plant engineering capacity to provide for new steelworks extensions, all these are in hand.

It will be noted, therefore, that while the threats of the forces of domination have ceased, the struggle is not yet over ; the nations must devise a new world in which freedom prevails in preference to establishing peace by fear. Britain must take a leading part in trying to satisfy the hope of mankind that saner methods will be adopted to establish a secure peace. She can do much by putting her own house in order and by raising her industries to a high state of competence.

The Manufacture of Steel

A 33-MINUTE documentary film on steel recently commenceed to be shown to the public at the Gaumont, Haymarket, London. It is presented in colour and while British documentary films are usually of a high order, this film is exceptional in that respect. The British Council, which sponsored the project in association with the British Iron and Steel Federation, are to be congratulated on their initiative, while Technique Film Productions in association with the Film Producers' Guild, Limited, have succeeded in presenting a very difficult subject in a worthy manner.

In an effort to regain export markets in the post-war era the use of films will doubtless play an important part and this film " Steel " is presented as the first major production of its kind. It is the first attempt made in this country to film the making of steel in colour. Under normal conditions steelworks certainly do not provide ideal conditions for photography and since this film was made under war-time blackout conditions, it will be appreciated that some almost insuperable difficulties were encountered. It is worthy of note that colour photography calls for nearly five times the amount of light than is normally required for black and white photography.

There is just one criticism we feel it necessary to make : we have been unable to note in the commentary any reference to the fact that the major discoveries in the manufacture of steel were initiated in this country. This fact should not be omitted from a documentary film of this character. Otherwise this film is both interesting and informative : indeed, it is probable that the majority of the people who see it projected on the screen will be thrilled.

A still from the film "Steel" by The Technique-Film Producers' Guild

Effect of Various Surface and Structural Conditions on Nitriding

By F. F. Dodson

With the object of reducing the time factor, generally associated with the nitriding process, experiments have been carried out in an effort to relax preliminary precautions usually considered to be necessary to produce the desired case and obtain the physical properties sought in the core. This report surveys the effects of various surface and structural conditions on the results obtained after nitriding DTD.87A and DTD.306 material, including different methods of operating the process.

THESE experiments were carried out after doubting the widely accepted statement that defects in the nitrided "case," e.g., soft spots, are due to the surface of the steel being either greasy or possessing an oxide skin. The former due to handling, and the latter through not having purged the container free from air before heating, or through the seal "blowing" during the cycle to admit air, this again being another source of oxidation. Oxidation has been listed, as it were, to be the chief fault, as it is supposed to prevent the penetration of atomic nitrogen into the surface of the steel.

Experimental Work

Experiment No. 1. Samples of DTD.87A were obtained and treated as follows:—

Heated in air circulating furnace:—

No. 1	at 180° C. × 1 hr.
No. 2	at 250° C. × 1 hr.
No. 3	at 300° C. × 1 hr.
No. 4	at 350° C. × 1 hr.
No. 5	at 450° C. × 1 hr.
No. 6	at 500° C. × 1 hr.

Thus each component was covered with a different depth of oxide ranging from a straw colour to a black fairly heavy scale. The pieces were then placed in a nitriding container, together with a production load, and processed at 520° C. for 20 hours. After the process, the samples numbered 1 to 4 were seen to have been completely "cleaned" free from the oxide colours and possessed a grey matt finish. The other pieces (5 and 6) still had scale adhering to the surface, but this scale had been changed to a "free" type which rubbed off quite easily. All components were then checked for hardness and case depth. The hardness on all pieces was above 1,000 V.P.N. Samples 5 and 6 were very carefully checked for soft spots and irregular depth, but these faults were entirely absent.

Experiment No. 2. Further samples were then prepared:—

No. 1A. The surface chemically cleaned, then smeared with grease in one area.

No. 2A. Surface oxidised as (No. 3) and grease applied in one area.

No. 3A. Surface oxidised and grease applied all round outside walls of component, leaving top section clean from grease.

The samples were then nitrided.

Results were that No. 1A, which had been cleaned and grease applied in one area, was over 1,000 V.P.N. all over. No. 2A, oxidised and greased in one area was also above 1,000 V.P.N. all over. No. 3A, oxidised and greased heavily all over, gave 940 to 970 V.P.N., with an even case depth as with former pieces.

In view of these results, it was decided to process a load of DTD.87A without first purging the container free from air, as efficient purging is regarded as being an imperative part of the process.

Experiment No. 3.—The samples were placed in the container which was sealed with chrome ore and immediately charged into a furnace operating at 500° C. The ammonia gas was then passed through, but owing to the seal being repeatedly broken (caused by the excess pressure set up by the rapid expansion of the air and gas inside the container) the rate of flow had to be reduced to 1 cu. ft. per hour. Time taken for the container and load to reach 500° C. was 1¼ hrs., and during this period a check on the percentage of air present in the container was taken every 15 mins. The first check gave 75% air, 15 mins. after the container had been in the furnace. By this time the pressure inside the container had lessened, which allowed an increase in the rate of flow of ammonia gas. This was adjusted to 5 cu. ft. per hr. A second check on the air content gave 60%. The third check taken gave 25%. After this check had been taken the temperature of the container and load was over 350° C., and as ammonia dissociates above this temperature, further checks on percentage of air would not be specific, as the result would be percentage of air plus hydrogen and nitrogen. However, checks were taken until the result was 3% which increased to 8% within 15 mins. This indicated that dissociation was becoming rapid, and the rate of flow was then reduced to 4 c.f.p.h. Dissociation checks were taken every 2 hrs., these ranged from 13 to 15%. The temperature of the load was 500° C. and the ammonia gas was passed into the container at 4 c.f.p.h. at a reduced pressure of 2½ lbs. Incidentally, the back pressure advocated for nitriding is 1 in. minimum, but the back pressure used during this process was kept at ¾ in. After 20 hrs. the container was immediately removed from the furnace and the rate of flow of ammonia increased to counteract the suction action set up by the rapid contraction of the gas inside the container. When the temperature was below 350° C. the ammonia was turned off and the container allowed to cool. The appearance of the samples on removal from the container was perfect, being of a grey matt finish.

A sample was picked at random and checked for hardness, which was 1,100 VPN and was carefully inspected for soft spots, which were entirely absent. This piece was sectioned and a micro examination revealed an even depth of nitrided case 0·005 in. thick.

The number of samples processed totalled 33, each was carefully checked for hardness, and with one exception all gave over 1,000 VPN. The particular sample giving low readings was sectioned and micrographic examination revealed that there had been a penetration of nitrides to 0·005 in., but as this sample had not fine machining lines on the outside surface much of the " case " had been removed in preparing a suitable surface for hardness determination.

All other samples were again inspected, but were found to be free from machining grooves.

The specification for DTD.87A gives the following chemical analysis :—

C	Si	Mn	Ni	Cr	Al	W
0·35–0·45	0·45	0·65	0·25	1·40	0·90–1·30	1·0 opt.

Since it is generally acknowledged that aluminium is is the chief constituent for producing the high hardness by this process, it was decided to apply the previous methods of unorthodox practice to a batch of DTD.306 material in which aluminium was not a constituent. According to the specification the chemical analysis of this material is as follows :—

C	Mn	Ni	Cr	W
0·15–0·35	0·65	0·30	2·5–3·5	1·0 opt.

It should be noted that the specification for DTD.87A calls for a minimum hardness of 1,000 VPN, while that for DTD.306 calls for a minimum hardness of 800 VPM.

Experiment No. 4.—Samples of DTD.306 was prepared as follows : 24 chemically cleaned, and 24 dipped in quenching oil and allowed to drain for 10 min., after which they were placed together with the clean samples in the container. The container was then sealed with chrome ore and processed in the same manner as No. 2 experiment, the only difference being that 520° C. was the temperature used instead of 500° C. After the process the samples that had been oiled had a " black leaded " appearance. However, on checking, all the samples were well above 800 VPN., and of even case depth. Tests were then made to check the effect of nitriding samples that had been burnished and polished, thus having a surface that would appear to be impervious to gases.

Experiment No. 5.—Material used DTD.87A. The samples immediately after polishing were cleaned and nitriding commenced. The process was carried out in an orthodox manner, having first purged the container free from air before heating to 500° C. This was to ensure that the polished surface of the samples would not oxidise, and such oxidation be subsequently reduced by the atmosphere when at temperature to produce a porous surface which would readily absorb nitrogen. The results, after the process, showed that the hardness of these burnished and polished samples was over 1,100 VPN. Each piece was sectioned and examination showed the depth of penetration to be uniform in each sample, it being 0·008 in.

Further experiments were carried out to check the effect of various structures on the nitriding of DTD.87A. Samples prepared were those that had received correct treatments and samples that had received pseudo heat-treatments prior to nitriding. The treatments and results are as follows :—

The results indicate that, whilst a fully sorbitic structure is desirable for core properties and also a necessary structure to reduce distortion during nitriding, it does not appear that the surface hardness or depth of a nitrided case is impaired or improved by various structures that result from heat-treatments.

Batch	Heat Treatment	Hardness 10 Kilo.	Nitriding Process.	Hardness after Nitriding 5 Kilo.	Case Depth In.
1B	900° C. oil quenched .. Tempered 620° C. × 1½ hr.	348 VPN.	20 hrs. @ 520° C.	1100–1120	0·007
2B	900° C. oil quenched .. Tempered 500° C. × 1 hr.	457 „	„ „	1100–1120	0·007
3B	900° C. oil quenched .. Tempered 450° C. × ¾ hr.	484 „	„ „	1100–1120	0·007
4B	900° C. oil quenched .. Not tempered.	585 „	„ „	1100–1120	0·007
5B	850° C. oil quenched .. Not tempered.	564 „	„ „	1100–1120	0·007
6B	850° C. oil quenched .. Tempered 600° C × 1 hr.	353 „	„ „	1100–1120	0·007

The results obtained from these experiments proved that a considerable amount of time could be omitted from the process. This is illustrated by comparing two methods, one as recommended by nitriding specialists, and the other by an unorthodox method.

Number of components, 100 ; size approx. 2½ in. × 1 in. dia. ; size of container, internal dimensions, 40 in. × 18 in. × 10 in. deep.

Orthodox Method—100 Components.

Components tin-plated where necessary—5 hrs.
Chemically cleaned—1 hr.
Purge container to at least 3% air using max. rate of flow of 4 cu. ft. per hr. to prevent blowing of seal—3 hrs.
Charge in cold furnace and bring to temperature of 500° C.—520° C. Time taken—2¼ hrs.
Process 20 hrs.
Current to furnace cut off and door opened.
Container removed when at 300° C.
Components removed when container handleable—Time, 4 hrs.*

Total Time—35¼ hrs.

Unorthodox Method—100 Components.

Components plated as No. 1 Batch—5 hrs.
Not chemically cleaned.
Purge container with highest rate of flow possible.
NOTE—This often blows the chrome ore seal, which is immediately repaired by vibrating container with rubber mallet. Time taken to reach 0%—10 min.
Charge into furnace operating at 520° C. and rate of flow stopped until container is above 200° C. then set at at 4 cu. ft. Time taken to reach temp. of 520° C—45 min.
Process for 20 hrs.
Container removed from furnace immediately, and rate of flow increased. Air blowers directed on container for rapid cooling. Time taken—1 hr.

Total Time—26 hrs. 55 min.

Difference : 35 hrs. 15 min.
26 hrs. 55 min.

8 hrs. 20 min.

Adoption of Unorthodox Method

After reproducing the satisfactory results by nitriding as quoted in method 2 (unorthodox), it was decided to process all production components by this method, and after two months successful production, this method was permanently adopted. The writer considers that

* The air blower to reduce cooling time can surely be used by this method too! —Editor.

soft spots present on components after nitriding are due to the material having been processed in the presence of stagnant gas. This was proved with the plant that was used for these experiments, as the first five loads of components that were processed in this plant were patchy in hardness and case depth. The method of process was in the usual orthodox manner, keeping the dissociation at approx. 30%. To obtain 30% the rate of flow had to be reduced to 0·8 cu. ft. per hr. The trouble at first was not attributed to the method of processing, but to the preparation of the components, and as each of the five loads were prepared by various methods, it was decided to increase the rate of flow of the ammonia gas to 1½ cu. ft. per hr. This gave more uniform results, and it was also found that by reducing the back pressure from 1¾ in. to ¾ in. using 1½ c.f.p.h. improved results. Therefore, further loads of material was processed using 3 c.f.p.h. resulting in a perfect load of components all having a hardness of over 1,100 VPN. and an even case depth of 0·007 in. Apart from extensive checks with the Vickers' machine, each component was lightly shot-blasted. Soft areas show a roughened effect under this treatment, while the surrounding hard material has a smooth burnished appearance. Provided the shot-blasting is done with discretion, it is an excellent method for checking large batches of small components, especially cylindrical types where the inside and outside surfaces are required to be hard.

Conclusions

The writers' explanation why nitriding is possible regardless of the surface condition, is that the atmosphere in the container, when in process, is slightly reducing, thus any oxide film present on the stock being nitrided is reduced to H_2O, whilst grease, if any, is decomposed by the temperature to a porous coating, which does not restrict the penetration of nascent nitrogen sufficiently to impair the results.

Although the writer has substantiated his results using one type of plant and two kinds of steel, it is appreciated that such a method may not be applicable under different conditions, but it would be in the interest of metallurgists using the nitriding process to carry out similar experiments using their own particular equipment and materials.

Forming and Jointing Aluminium Alloys

Spinning and Panel Beating of Aluminium Alloys

DESPITE the enormous strides made in recent times in the forming of aluminium alloys by mechanical, mass-production methods, it is believed that the war years have seen no diminution in the use of methods of hand forming, such as spinning and panel beating, but rather, an actual increase. Probably because spinning and panel beating are both traditional crafts, little of an authoritative nature has been written on these methods of shaping the aluminium alloys, and it is to make good this gap in technical literature that this booklet has been compiled and published. At the same time, it is intended that it should serve as a general introduction to a discussion of forming methods as a whole.

The present work begins with a general survey of the forming properties of the aluminium alloys in which the phenomena of work-hardening, softening, and rain growth are discussed as far as possible in non-technical language so that they may be understood by workers engaged in spinning and panel beating. The heat-treatable alloys, and the effects of heat-treatment, are similarly considered.

Following this account of the fundamentals of forming, the spinning process is then described in some detail, lathes, speeds, chucks, hand tools and spinning technique being discussed, while the influence of the gauge of material and annealing is also dealt with. The account of panel-beating, which is defined as "a hand method of producing hollow forms by means of hammering," begins with a discussion of the types of blows which may be struck on sheet metal. The technique of panel-beating is then described, attention being paid to methods of hollowing and raising, planishing, wheeling, and the "split-and-weld" system of panel-beating. The account concludes with a description of the tools used in the craft.

The booklet is profusely illustrated by photographs, line drawings and schematic diagrams. The following may be singled out: the diagram showing the effects of heating on hardness and ductility; the photomicrographs showing formation of new crystals; the series of close-up photographs showing the four stages of spinning; the line drawings of hollowing and raising bowls and of forming puckers; the photographs of typical examples of panel-beaten work; and the line drawings of the panel-beater's hammers and other tools.

Riveting of Wrought Aluminium Alloys

Despite recent developments in joining techniques riveting remains the principal method of joining aluminium alloy sheet. This booklet of 48 pages reviews for the first time in a comprehensive manner riveting practice for these light alloys. After a discussion on the correct choice of rivet alloys, identification of rivets and the types of rivets covered by B.S. 641, 1935, and by the Society of British Aircraft Constructors, are described.

The design of riveted joints is discussed under the following heads: Strength of riveted joints; shear strength of rivets; bearing strength of riveted sheets; tensile failure; edge distance; and riveting pitch. Drilling practice is covered in a separate section.

Riveting practice is considered in detail and the hot driving of the larger sizes of rivets in duralumin-type alloy is described. Methods of rendering riveted plates pressure-tight are given. The correct choice of riveting tools, dollies, squeeze riveters, hydro-pneumatic squeeze riveters, pneumatic hammers and offset and extension fittings, is discussed.

An important feature of the booklet is the attention paid to rivets for special purposes, such as tubular rivets, "pop" rivets, "Chobert" rivets, "de Bergue" rivets, explosive rivets and cone-head rivets. A special section is devoted to automatic riveting practice, while there are chapters on the inspection of riveted work and the mechanical testing of rivets. The heat-treatment of aluminium-alloy rivets is discussed in an appendix.

Copies of these booklets may be obtained from the Aluminium Development Association, Union Chambers, 63, Temple Row, Birmingham.

Correspondence

The "Set Test" Elastic Limit

The Editor, METALLURGIA.

Dear Sir,—I believe that your readers would like to know of some careful work with the electron micrometer, upon this vexed—but, after all, easily settled—question of the literal elasticity of the metallic aggregate. Hence, I send you a letter I have recently received from America in the hope that you will be able to find room for it in your pages.—Yours faithfully,

Putnoe Lane, A. C. VIVIAN.
Bedford.
July 18, 1945.

Dr. A. C. VIVIAN,
BEDFORD.

Dear Dr. Vivian,—I so enjoyed your paper titled "The Shape of a Material's Reactions to Force" in the March METALLURGIA that I felt impelled to write and express my gratitude to you. The necessity of gaining basic knowledge of the stress—strain relationship and eliminating this hodge-podge of uncorrelated data is growing greater every day as the mass of that data becomes larger.

We manufacture precision springs from beryllium copper and thus are forcibly reminded hourly that such conceptions as Hooke's law, proportional limits, constant elastic moduli, etc., are variables with assigned values only indicative of the method and accuracy of the testing devices used.

In attempting to evaluate materials and heat-treatments we use "set test" method that I think will be of interest to you. The spring material is set up as a cantilever and its initial free position noted with a sensitive electronic micrometer which can read this free position with a sensitiveness of ·00005". A dead weight load is applied for a fixed time (such as ten seconds), removed and the new free position immediately noted. This is repeated for a series of loads and this difference in free position or "set" is noted for each load. The "set" is plotted against load or calculated stress. The set is proportional to the load until a value is reached roughly corresponding to the conventional elastic limit of the material. The "set test elastic limit" is then used as an evaluation of the material or heat-treatment. The evidence is that no matter how low the stress there is still introduced some set, although for very low stresses it may be beyond the sensitivity of the instrumentation.

We then use a similar specimen and selecting a load slightly below this "set test elastic limit" we will repeat the test with a constant load and varying the time so as to plot a drift or room temperature creep test of the material stopping usually at the end of 100 hours which is usually sufficient to develop the rate of drift plotting the set against the log. of time. We also at times plot the reverse of this process on the recovery curve after the load has been removed.

The rate of drift is used to evaluate the stability of the spring material as it affects the retention of calibration in instruments. It is, of course, important that these tests are run at controlled temperatures, if consistent results are wanted.

We realise that we are as yet gaining only comparative data and not basic data and attempts to convert to basic data involve specimen design and control of variables but this type of approach has been of much more value to us in understanding and controlling our spring quality than the more conventional approach.

When springs are deflected within the usual elastic limits, there are three elements to the subsequent strain :—

1. An elastic deflection (which may or may not obey Hooke's law).
2. A permanent set not recoverable.
3. A drift or creep with time under load that is recoverable.

For purposes of measurement it is difficult to separate 2 and 3 except arbitrarily.

The development of a true stress—strain, time—temperature curve or curves face the same difficulties we have been facing. We hope some day to get the answer or at least part of the answer. The aid of other aspirants, even the comfort of knowing of fellow voyagers, is encouraging; thus my presumption in writing you. I wonder if you would be so kind as to send me copies of your other papers to which you refer. I would certainly appreciate the opportunity of reading them. —Sincerely yours,

Instrument Specialties Co., Inc.,
Little Falls, HAROLD G. WILLIAMS.
New Jersey. Chief Metallurgist.
June 12, 1945.

Obituary

WE regret to announce that Mr. J. E. Betts, who had completed almost 45 years service with the British Thomson-Houston Co., Ltd., died suddenly at his home in London recently.

After holding engineering appointments in South Africa, Mr. Betts joined the outside construction staff of the BTH Co., in July, 1900, being first employed on the Bristol Tramways Electrification scheme, then on work in connection with the Glasgow Corporation Tramways Power Station, Pinkston; the Ayr Corporation Tramways; The Hamilton, Motherwell and Wishaw Tramways; the Sheffield Corporation Tramway Power Station at Kelham Island; and elsewhere. In 1902 he was transferred to the construction staff at Rugby Works, and later was appointed manager of Factory Production, Stores, and Order Departments. In 1918 he was appointed Supervisor of Purchases for the BTH Co., and in April, 1931, became Chairman of the Group Purchasing Committee of Associated Electrical Industries Ltd. He held these appointments until his death.

MR. JOHN ALEXANDER BRAIDWOOD, B.Sc., A.M.I.E.E., Chief Electrical Engineer, Dorman Long & Co., Ltd., Cleveland Iron and Steelworks, whose death was announced recently, was only 39. He was held in high esteem by his colleagues, having joined the Company in 1932, as assistant electrical engineer at Cleveland, becoming chief electrical engineer a few months later. For some years he was with Metropolitan-Vickers Electrical Co., Ltd., before joining the Dorman Long organisation.

The Progress of Magnesium and its Alloys in Britain—1924-1945

By Major C. J. P. Ball, D.S.O., M.C., F.R.Ae.S.

Chairman: Magnesium Elektron Limited,
Managing Director: F. A. Hughes and Co., Ltd.

Magnesium is the lightest of the metals now available to designers and engineers. Isolated for the first time by an Englishman, Sir Humphrey Davy, in 1808, some 16 years before the discovery of aluminium, it is silvery white in colour and has a specific gravity of 1·74, only two-thirds the weight of aluminium and one-quarter to one-fifth the weight of steel. It is the eighth most abundant element and the sixth most abundant metal, and is generally available on the earth's surface in the form of magnesite or magnesium carbonate in dolomite, of which latter there are immense deposits in the British Isles.

Since 1938 methods have been worked out and plants are in operation in Britain for leaching out magnesium oxide from dolomite by the use of sea-water so that magnesium metal and alloys have now become an all-British product.

THE essential foundation for the creation of any new manufacture is an assured market for the product, consequently, the history of the formation and growth of a magnesium industry in Britain during the past twenty-one years is almost entirely a story of the pioneer work necessary to develop such a market for magnesium and its alloys as would warrant the heavy capital expenditure required to provide plants for extracting the metal from its ores and refining and alloying to meet consumers' requirements.

This last quarter of a century has seen remarkable progress in scientific and technical knowledge concerning the element "Magnesium," the lightest of all metals available for engineers, and the ores in which it is most commonly found. Processes of extraction and methods of fabrication have been developed which have permitted the recovery of the metal from the ore and its conversion into alloys for constructional purposes in quantities and at prices which, at the commencement of this period would not have been credited as being possible of achievement.

Much of the growth of production in both enemy and allied countries has been due to the vital importance of magnesium for reducing the weight of aero-engines and aircraft, and for special armament purposes. In some countries over-calculation of requirements resulted in excess productive capacity, but, as is always the case, the energy, initiative and capital poured into the development of magnesium and its alloys has enabled the industry to achieve a degree of progress within this comparatively short period far in excess of what would have been possible during normal times.

The last war saw the erection of a small plant by Johnson Matthey and Vickers at Wolverhampton to provide the magnesium powder required for flares and tracers, but the process employed was too costly to permit of the use of the materials for commercial purposes, and the material itself too unsatisfactory in its properties for engineers to use for constructional purposes; soon after the end of that war, therefore, the plant was closed down.

From 1919 onwards till 1936 Britain imported most of its magnesium requirements, mainly from Germany, but some from the Dow Company of America.

In 1920, F. A. Hughes and Co., Ltd., the parent company of Magnesium Elektron Limited, began to try to find a market in Britain for the magnesium and magnesium alloys produced by the I. G. Farbenindustrie, of Germany, the largest manufacturers of magnesium in Europe. The road was long and hard. At that time the magnesium alloys then available were still too subject to corrosion. No technical books or data were available for designers, and fabricators in the wrought or cast field had little, if any, knowledge of the special techniques required to produce sound and satisfactory wrought or cast materials for consumers. To engineers generally magnesium was almost an unknown material, and unlikely to be of interest to them in their construction problems.

With the object of improving this position and placing available information in a practical form at the disposal of engineers and fabricators, Hughes began to collect data to prepare a technical handbook. Meantime, substantial progress had been made by I.G. in improving its magnesium alloys and technique of fabrication, and in lowering the initial cost of the metal. In England, Hughes had been greatly assisted in the cast field by the support of and work done by Mr. E. Player, managing director of Sterling Metals, Ltd., light alloy founders, of Coventry.

By 1926, the corrosion resistance and other physical and mechanical properties of Elektron magnesium alloys had been so improved by the discovery of the virtues of manganese as an alloying constituent that H. M. Air Ministry, granted a first D.T.D. Specification, No. 59. In 1928 Hughes published a technical handbook for designers and engineers, the first ever published in Britain dealing solely with this new metal magnesium and its alloys, the latter distinguished by the trade mark "ELEKTRON."

During the next few years it was discovered that microporosity was more prevalent in the high zinc content alloys originally used containing 6% aluminium, 3% zinc, remainder magnesium. As a result new alloys were developed containing higher contents of aluminium and lower contents of zinc which became the well-known alloys A.8 and AZ.91, 8 — 11·5% aluminium, 0·4% zinc, 0·3% manganese, remainder magnesium. Progress

Fig. 1a.—Large Diesel-engine crankcase cast in Elektron magnesium alloy. The overall sizes are 8 ft. × 3 ft. 3 in. × 1 ft. 6 in. and the weight 6 cwt. In aluminium alloy the weight of a similar crankcase is approximately 10 cwt. The crankcase on the left, shown for comparison, is for a 25 h.p. motor car engine.

Fig. 1b.—Typical 6-cylinder commercial vehicle crankcases, for petrol and oil engines, cast in Elektron magnesium alloy. The weight of the largest casting is 168 lbs.; a similar casting in aluminium alloy would be 284 lbs.

in discovering the causes of microporosity was accelerated by the determination of the Dunlop Rim and Wheel Company, Ltd., to obtain Elektron castings of high quality for their aircraft landing wheels, which have given such magnificent service to the R.A.F. and Fleet Air Arm. The consequent tightening of inspection led to the introduction of break-up tests, i.e., the first few castings made of a new design are broken up after heat-treatment under an hydraulic press. This discloses the position of any microporosity and is a form of testing which has helped greatly to improve foundry practice and establish quality production.

The Finance Act of 1928 passed Regulations licensing motor transport vehicles by weights, and as a result all users and manufacturers of heavy vehicles sought to reduce unsprung weight. This resulted in a large demand for castings, such as crank cases, gear boxes, back axle castings, etc. The castings were sold at prices per piece which compared favourably with those then ruling for aluminium.

Licensing weight restrictions on transport vehicles were not an unmixed evil. The necessity for lightening the dead weight referred to above inevitably resulted in better running efficiency, exemplified by longer tyre life, higher braking efficiency, lower fuel consumption, etc., or conversely, by heavier pay loads. These improvements in performance, of undoubted and important advantage to all transport operators, were obtained by making free use of the ultra light "Elektron" magnesium alloys in the construction of the vehicle.

Sales grew steadily and in 1934 Hughes published the second edition of its technical handbook.

Production from the Ores

By 1935 Hughes' sales of pure magnesium and Elektron alloys had reached a figure of around 100 tons per month, which appeared to warrant the erection of a metal extraction plant, and in view of the "red light" showing politically in Germany, and the vital need for magnesium production in Britain, Hughes decided to try to persuade I. G. Farbenindustrie to assist them to

build a plant in England to extract the metal from its ores.

Magnesium Elektron Limited, with a capital of £400,000 was formed by Hughes for this purpose, and proceeded to arrange to purchase outright all the patents and "know how" of the I. G. for the magnesium field within the British Empire.

A site was found at Clifton Junction, near Manchester, and contracts arranged for supply of electric power, chlorine and magnesite at prices which compared reasonably well with those of the I.G. and capital provided to buy the patents, processes and "know how" from I. G. for the British Empire, and to erect and operate a plant of capacity of 1,500 tons of magnesium metal per annum.

Fig. 2.—The Clifton Junction plant of Magnesium Electron Limited.

Work was *started in March*, 1936, and the first metal was *produced in December*, 1936; the magnitude of this undertaking can be gauged from the fact that it involved the expenditure within the period named of about £250,000.

H. M. Air Ministry shortly thereafter instructed M.E.L. immediately to extend its plant by 2,500 tons annual capacity, the Government providing the capital, and M.E.L. leasing and operating the plant. Using the facilities and staff of M.E.L., work was commenced in January, 1937, and the new extension which cost approximately £475,000 *started production in January*, 1938.

During this period Hughes, at the request of the Air Ministry negotiated the purchase of 4,250 tons of magnesium from Germany for our own R.A.F. re-armament programme and most of this was delivered from shadow factories of the German Government re-armament programme. It is now interesting to recall that this material was converted into: (*a*) incendiary bombs and (*b*) the aircraft that carried them was later returned by the R.A.F. literally as "coals of fire on German heads."

In 1936, Murex Limited commenced production of magnesium metal by a thermal process using calcium carbide as a reducing agent. This plant was to have a capacity of 1,000 tons per annum, later increased to 2,000. During the period 1936 and 1938 the Magnesium Metal Corporation were erecting a plant to operate a carbo-thermic process at Swansea, but owing to technical problems with the plant and process production was slow in commencing.

In 1937 Hughes issued a 3rd edition of the Handbook. In the same year the Department for Scientific and Industrial Research issued a valuable monograph, "Magnesium and Its Alloys," by Dr. J. L. Haughton and W. E. Prytherch.

Between 1939–40, realising the increasing need of designers and engineers for authoritative information and data about magnesium and its alloys, the technical staffs of F. A. Hughes and Co., Ltd. and Magnesium Elektron Limited translated and published with comments Adolf Beck's *Magnesium und seine Legierungen* (Technology of Magnesium and its Alloys) a work which contained most of the German technique available at that time. In 1944 Bulian and Fahrenhorst's *Metallographie des Magnesiums und seiner technischen Legierungen* (Metallography of Magnesium and its Alloys) was similarly translated and published.

"Magnesium Review and Abstracts," a publication of F. A. Hughes and Co. Ltd., and Magnesium Elektron Limited, devoted to original papers of interest to the magnesium industry has been continued in limited form during the war, but will be readily available as soon as paper supplies permit. I have drawn attention particularly to the work done in the creation and circulation of technical literature on magnesium and its alloys because this forms a most essential and important part of the development of any new industry.

Realising that war with a Continental power would probably prevent any importation of magnesite from Greece, in 1937 M.E.L. sought the co-operation of British Periclase in solving the problem of extracting magnesia (MgO) from dolomite deposits in Britain.

The problem was solved successfully and the first supplies of magnesia for magnesium extraction were recovered from dolomite and sea-water in 1938. Despite U.S. claims, M.E.L. first extracted magnesium metal from the sea and thus made the British magnesium industry independent of supplies of imported raw materials.

The vital importance to Britain of this success cannot be too heavily stressed because it makes available for Britain's future air fleets unlimited supplies of magnesium metal, the lightest of all materials available to aircraft constructors.

Fig. 3.—An aerial view of the large plant designed and built by Magnesium Elektron Limited for the United States Government. This plant, designed to produce 50,000 tons per annum, produced its first metal ten months from the day the ground was broken.

In 1940, because of the acute world shortage of magnesium and its alloys the following additional productive capacity was authorised by the Ministry of Aircraft Production to be built as shadow factories as rapidly as possible :—

(1) M.E.L. was instructed to build additional plant to produce 5,000 tons per annum at Clifton Junction.

(2) Murex Limited was instructed to produce 5,000 tons per annum at Moss End.

(3) International Alloys Limited, with a new thermal distillation process using aluminium ferro-silicon reducing agent, was instructed to produce 5,000 tons near Cardiff.

All three plants were intended to come into production in early 1941 as supplies of magnesium alloys were urgently needed to meet R.A.F. expanded requirements of aero engines and air frames, aircraft landing wheels, incendiary bombs, and magnesium powders for flares and tracer ammunition.

These extensions actually reached full operation approximately as follows :—

M.E.L.	1941
Murex	1942
International Alloys	1943

In 1941 Magnesium Elektron Limited was requested by the U.S. Government to design, build, train the operating staff for, and bring into operation, a magnesium metal and alloy production plant near Boulder Dam in the State of Nevada making use of the cheap power available from Boulder Dam and magnesite deposits at Gabbs. The largest magnesium production unit in the world, designed to produce 50,000 tons per annum of metal alloys was built under M.E.L. technical direction, and produced its first metal in the astonishingly short period of ten months from the day the ground was broken. This was a great feat of rapid construction in a desert country. Under the direction of Basic Magnesium Inc., a company controlled by the well-known Anaconda Copper Mining Company, the plant operated successfully and ran throughout its life at roughly 10% above estimates. It produced nearly 90,000 tons of metal and alloys and was then shut down by the U.S. authorities because production exceeded demand. A general view of this large plant is reproduced in Fig. 3. *This was a great contribution by Britain to the allied war industry.*

In 1942–3 Magnesium Elektron Limited designed, built and operated a 10,000 tons production plant at Lowerhouse, near Burnley, for M.A.P. The completion of this unit brought the total possible production of magnesium metal in Britain to around 33,000 tons annual capacity .

As the demand for magnesium products became satisfied, and as the favourable progress of the war resulted in production exceeding demand, production units in Britain have been steadily closed. Because of the severe restriction imposed on the sale of magnesium alloys for civil usage, markets will have to be re-created, consequently it is probable that the post-war period will, for a time, find the production of new metal in Britain reduced to around 4,000 tons per annum from M.E.L's original plant at Clifton Junction, and the Magnesium Metal Corporation, Swansea.

Fabrication

Owing to the steadily increasing demand, both prior to and during the war, many more fabricators commenced to produce magnesium alloy castings, and the tonnage produced was spread over a wide area.

For various reasons progress in the wrought field was not so rapid, of which the chief would appear to be the difficulty of fitting in the production of the comparatively small quantities of magnesium alloys, which require a totally different technique, to production programmes in works fully occupied with aluminium alloys.

Fig. 4. The Lowerhouse factory of Magnesium Elektron Limited

Experience had shown too that the mechanical properties of the wrought alloys lagged behind those of the aluminium alloys, so that apart from special applications such as oil and fuel tanks, in which field Essex Aero Limited of Gravesend have done splendid work; pilot seats, chairs and internal equipment for aircraft, in which L. A. Rumbold and Co., Ltd., led the field; and a large usage by certain aircraft firms such as de Havilland and Westland Aircraft for fuselage and air frames—development has been limited.

By far the largest proportion of magnesium fabricated parts, produced in Britain during the war for the R.A.F. and other services (a proportion believed to exceed 80% of the whole) was supplied by the "Elektron Group" consisting of Magnesium Elektron Limited, and its licensees, Messrs. Sterling Metals Ltd., Birmingham Aluminium Casting (1903) Co., Ltd., James Booth and Co. Ltd., J. Stone and Co. Ltd.; Birmetals Ltd., in addition L. A. Rumbold and Co. Ltd. were users of the Elektron Trade Mark, and Essex Aero Ltd. mainly used Elektron alloys in their constructions.

Other companies who fabricated magnesium alloy castings were :—

Magnesium Castings and Products Ltd.,
Aeroplane and Motor Aluminium Castings Co., Ltd.,
Magnal Products Limited,
Leyland Motors Limited,
Airedale Light Alloys Ltd.
Kent Alloys Ltd.

In his address to the shareholders of Birmid Industries Mr. Cyril Maudslay, the chairman, gave the following interesting figures: "Our Elektron magnesium foundries, the largest in the country, have worked under high pressure, producing 16,079 tons of Elektron castings for aero engine and aeroplane constructors from their sand foundries alone, added to which they made 4,247 tons of gravity and pressure die castings, giving a grand total of magnesium Elektron castings in all forms of 20,326 tons—a great achievement when it is remembered that magnesium, weight for weight, is four times the bulk of steel.

This leads me to the mention of one service in which our Group was pre-eminent—I allude to the supply of aircraft landing wheels to the extent of 95% of the total requirements of the British Aviation Industry. Of these, Sterling Metals made approximately 700,000 and Birmingham Aluminium casting 230,000, giving a grand total of 930,000 landing wheels, with practically no service failures under the most severe conditions. Another striking contribution was the supply by Birmal and Sterling Companies of 47,000,000 magnesium incendiary bomb castings during the war period, at a peak production rate of over 2,000,000 per month.

Here I would like to make some special remarks on Elektron magnesium. It can be said that, in the national interest, there should be a wide expansion in the post-war world in the use of magnesium alloys. It cannot be too often pointed out that magnesium is the only engineering constructional metal in which this country is, and can be, **wholly self-supporting.** This can be said of no other metal in extensive use. The use of Elektron magnesium is of the first importance in all forms of transport where the power weight ratio is a serious factor."

As a further instance of reliability of Elektron castings in the aircraft field it is interesting to record that Sterling Metals have supplied thousands of crankcases for the D.H. Gipsy Six, the first engine authorised by the director of engine development to run 1,500 hours between overhauls.

During the war much progress has been achieved in improving and standardising the quality of the alloys, but so far as is at present known the same type of alloys continue to be used both here and in the United States as were being used pre-war. Table below shows the standard materials :—

CASTING ALLOYS.

Type	Nominal Alloy Content %	D.T.D. Specification	Trade Designation	State
Mg–Al–Zn	8 Al, 0·4 Zn, 0·3 Mn.	59A	Elektron A.8	Sand and die cast.
	9·5Al, 0·4 Zn, 0·3 Mn.	136A	Elektron .. AZ.91	Sand and die cast.

WROUGHT ALLOYS.

Mg–Al–Zn	6 Al, 1 Zn, 0·3 Mn	259	Elektron AZM	Extruded bar
	6 Al, 1 Zn, 0·3 Mn	348	Elektron AZM	Tube
	8 Al, 0·4 Zn, 0·3 Mn	88B	Elektron AZ.855	Forging
Mg–Mn	1·5 Mn.. ..	142	Elektron AM.503	Extruded
	1·5 Mn.. ..	118	Elektron AM.503	Sheet

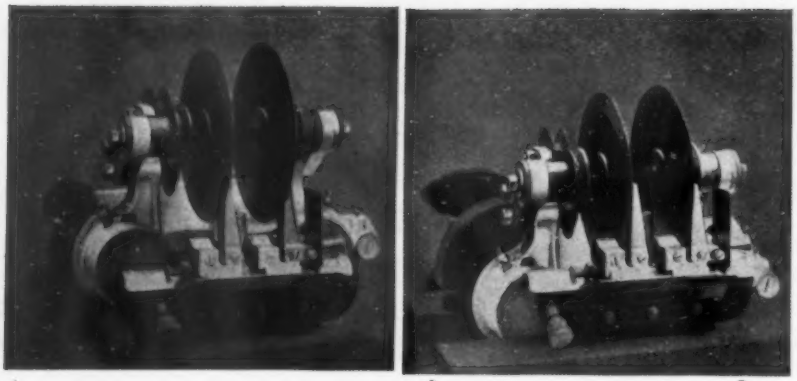


Fig. 5.—Cutting-off mechanism in cigarette machinery incorporating Elektron magnesium castings. It is claimed that the use of these ultra light castings increased output from 300 to 1000 per min.

Methods of fluxing and treating the metal have been improved and cheapened and generally very much more has become known about the fabrication and machining of these alloys. The breadth of application of magnesium alloys may be gauged by the fact that British Standard specifications are now being drawn up for them.

Thousands of tons of magnesium alloys have been handled successfully by works' personnel who before the war thought of magnesium, if they thought of it at all, solely as a ribbon or powder for photographic purposes. This usage must prove of value in forwarding the growth of post-war consumption as so many more engineers have come to realise, from personal experience, the attractive qualities of magnesium alloys.

These ultra-light magnesium alloys have certain outstanding advantages in this mobile age in which people talk increasingly of the problems of transport and traction. Low weight and good mechanical properties provide the designer and engineer with a strength : weight factor that calls insistently for consideration where improvement of pay load is demanded.

Before the commercial usage of Elektron magnesium alloys was prohibited by the Air Ministry, because all supplies were required for the R.A.F., these alloys were being employed successfully for a wide variety of purposes :—

In the private car, motor-bicycle and heavy vehicle industry for parts and cases of all kinds, gear, crank, axle, oil, pump, etc.

In the aircraft industry for engine parts and crankcases, for landing wheels, for welded petrol and oil tanks, for cabin furniture (tubes), for fairings and cowlings.

In the electrical industries for parts of motors, trams and buses, with the object of achieving improvement in the power : weight ratio with an increase in acceleration and maximum pay load.

In the machine tool industry for portable tools, rammers, compressors, and various parts of machine tools and welding sets.

In the textile industry for high-speed moving parts of standard weaving and knitting machines.

In the wireless industry for portable receiving sets and mobile transmitters.

In the scientific industries for field glasses, cameras, surgical and optical instruments.

For industrial and household equipment, such as air conditioning, conveyers, elevators, excavating equipment, foundry equipment, hoists, oil well equipment, scaffolds, furniture, office equipment, photographic and printing equipment, business machines, ladders, lawn mowers, sporting goods and toys.

Industries generally were beginning to realise the outstanding advantages of lightness and strength, which the use of Elektron magnesium alloys offered them. Fabricators discovered that these cast and forged parts could be manufactured in serial production. Fabricators of sheet discovered that when they used the proper technique the alloys could be worked and welded into complicated shapes by unskilled personnel more rapidly than aluminium.

In the U.S.A. complete full-size wing panels were built entirely in magnesium for the North American advanced trainer, the SNJ–2. After experimental trials, which gave satisfactory results, thirty sets of wings were ordered for service tests by the U.S. Navy. These are still continuing and so far the wings have withstood satisfactorily all the tests. The actual saving effected by using magnesium instead of aluminium for the standard wing was 30 lbs., or approximately 14%.

Machinists and fabricators found that the exceedingly high machining speeds and free cutting properties of these alloys permitted considerable reductions in machining times, whilst the low weight per piece enabled each piece to be moved by hand through all operations from stores to assembly, an advantage which has to be experienced in order to be fully appreciated.

The expanded usage of the war years has broadened the knowledge and appreciation of the value of the ultra light weight magnesium alloys in industry generally on both sides of the Atlantic.

In the post-war period power/weight ratio, strength/weight ratio, and pay load are three points which will command the attention and occupy the thought of most designers and engineers working in the transport industries, whether as suppliers or operators.

Consumers of these alloys are now looking to the industry to supply them at prices which, piece for piece, will be at least competitive with aluminium, and which in mechanical properties on a strength : weight ratio should also be competitive with aluminium alloys. They are expecting further that the corrosion resistance of the alloys will be so greatly improved that it will approach that of the aluminium-magnesium group.

What can the magnesium industry reply to these demands ? The answer is vital because upon the industry's ability to meet them depends the acceptance of magnesium alloys as materials that can be used easily by designers and engineers in solving their problems of reducing weight and increasing pay load.

The pressure of the war years has accelerated the efforts of research and development staffs to overcome the natural difficulties inherent in the production of magnesium alloys of high purity and increased strength. As a result of constant effort and application, great progress has been made in the solution of these problems. Advances have been made in the preparation of alloys of high purity which have shown an astonishing improvement in resistance to corrosion as compared with those available to industry in the pre-war days. Alloys have been produced with materially higher mechanical properties and improved workability which should go far to meet the new targets set by industry.

Experience has shown it to be possible to bring the cost of production of pure magnesium and its alloys within the figures required to enable them to compete on a volumetric basis with aluminium, and recent results indicate the probability of substantially reducing present fabricating costs.

Provided these objectives can be achieved regularly in practice there would seem to be no doubt that magnesium and its alloys have an assured future, and before long they should come to be regarded by all engineers and constructors as those materials to which they will turn when called upon to solve any problems where lightness-cum-strength are required.

National Certificates in Metallurgy and in Applied Physics

THE announcements by the Ministry of Education of schemes for the award of ordinary and higher national certificates in metallurgy and in applied physics, which brings to fruition recommendations made in connection with the education and training in these subjects, will be of interest to many readers.

In connection with metallurgy, the Iron and Steel Institute, the Institution of Mining and Metallurgy and the Institute of Metals have combined to establish, in co-operation with the Ministry of Education, a scheme for awarding these certificates to successful part-time students who are engaged in industry or other pursuits connected with this science. The scheme comprises senior and advanced part-time courses of study, the former being a three-year course leading to the ordinary national certificate, while two further years of study will constitute an advanced part-time course, on the results of which the higher national certificate will be awarded.

There are provisions under which the first year of the senior course may be excused to a student who can show that he has previously received equivalent instruction, and also for a limited period after a scheme has been approved other exemptions may be granted so that students who have already been taking suitable courses may enter for the ordinary national certificate examination without undue repetition of their work. The conditions of the final year of the course, however, must be fulfilled.

The subject is of national importance. Everything possible should be done to enable the metallurgical industries of this country to hold their own in the new and difficult industrial conditions which are likely to prevail in the post-war period. The supply, education and training of a sufficient number of metallurgists are among the most important steps which will make this possible. Full details of the above scheme are given in a brochure recently issued, copies of which may be obtained from The Secretary, Joint Committee for National Certificates in Metallurgy, 4, Grosvenor Gardens, London, S.W.1.

The scheme for applied physics is sponsored by the Institute of Physics and follows somewhat similar lines to those for metallurgy in that three-year and later two-year courses of study are arranged. The course for the ordinary national certificate is intended to lead on to that for the higher national certificate, the award of which will be recognised as a definite stage towards the first rung of the professional ladder, the Associateship of the Institute (A.Inst.P.) With a rapid growth of physics in industry and in the different Government Services, it has been found that the existing courses in branches of engineering, in chemistry and so on, do not singly provide the combination of knowledge required by juniors in some branches of work which depend on the advances of science, such as for example, the physical testing of materials and the maintenance and use of instruments for the measurement and control of different processes. Space does not allow more than the barest outline of the type of courses that would be approved. The three-year part-time course for the ordinary national certificate must include mathematics, physics and chemistry, and in the first year a special course (not the orthodox engineering one) in workshop practice and drawing. The physics in the course is to be treated realistically and the principles are, whenever possible, to be illustrated by practical examples drawn from the industries in which the students are working.

The course in applied physics in the final year is to be related to the local industries. Although English is not included formally as a subject in the course, it is a part of the scheme that at all stages and in all classes attention is to be paid to its correct use. It is hoped in this way to help to train students to present written statements which are clear and concise, when in the course of their employment they are required to report on their work.

The course for the higher national certificate must be a two-year part-time one and must aim at reaching a standard in the several branches of physics corresponding to that required for a degree in the subject related to the student's daily work in local industry.

The schemes are of particular interest to industrialists, technical directors or managers, and research directors or managers dealing with matters of production or research, and to the principals of technical colleges and schools. It is also of interest to all young technicians who wish to equip themselves, by organised part-time study, with a knowledge of the fundamental principles of either of these subjects, with a view to qualifying for a certificate which will have a professional and national as well as a local value.

Crystalline Titanium Nitride

By V. P. Remin Ufan

As a result of investigations the production of crystalline titanium nitride by melting powdered material may be regarded as solved. Because of its hardness and resistance to wear it may be used for some purposes in industry as a substitute for diamond. The subject is reviewed elsewhere the main features from which are given in this article.†*

CRYSTALLINE titanium nitride can be made by the following four methods: (1) Direct nitration of metallic titanium, (2) Repeated melting of powdered material, (3) Distillation and condensation, (4) Precipitation from metal-solutions. For this investigation method 2 has been chosen, and, as a variation, method 4 proposed by J. J. Efremov (G.P.Z.).

Crystalline forms of titanium derivatives have been known for a long time.[1] Crystals were found in the products of blast furnaces and cast iron made from ores containing titanium. Stead[2] describes two different forms, TiCN + 3 Ti_3N of copper-coloured metallic lustre (s.g. 4·1 to 5·1), which is ascribed to Sorby, and a new mineral called "Cochranit," $Ti(CN)_2$ of blue colour (s.g. 4·7). Other metallurgists have found in iron titanium nitrides and cyanides of cubic characteristics and bright pink colours.[3] Considering the uniform distribution of smallest TiN particles Comstock concludes that titanium nitrides are easily soluble in iron.

D. I. Mendeleyev[4] states that titanium combines so easily with nitrogen that it is difficult to obtain it without nitrogen; nitrogen compounds are very stable and not volatile. He mentions that Friedel and Guerin in 1876 had already obtained titanium nitride by heating TiO_2 in a stream of ammonia whereby compounds of TiN_2 were formed of a hard brass-coloured mass (s.g. 5·18). A compound Ti_3N_4 is obtained from $TiCl_4$ by heating its fumes in ammonia. It is of copper-red colour and has metallic lustre. To the same group belongs the well-known Ti_2CN_4; it occurs as insoluble, sometimes well-formed cubic crystals (s.g. 4·3) and are of copper-red colour and metallic lustre.

Zhukov[5] concludes of his experiments that titanium and nitrogen from phases of composition and refers also to TiN, Ti_3N_4, and Ti_5N_6. The good electric conductivity justifies his definition of titanium and nitrogen combinations as phases of composition—since the electric conductivity of titanium-nitrogen compounds (as well as of Mn and Cr compounds) is of the same order is that of pure metals. The electric conductivity, however, of combinations of nitrogen with Mg, Ca, and Al, which form definite compounds, is negligible.

Ostroumov[6] found titanium nitride of the formula Ti_3N_6. Friedrich and Sittig[7] prepared titanium nitride mixed with carbon from TiO_2 in a stream of pure ammonia at a temperature of 1,250 deg. for 3 hours. Their material contained 76·1% Ti, 21·9% N, and 1·96% admixtures which corresponds to 98% TiN, based on the theoretical values for TiN: Ti = 77·4% and N = 22·6%. By melting in a hydrogen atmosphere they obtained a material of giit colour (s.g. 5·29, Mohs' hardness 9–10), with a melting point of 3,200° C. X-ray diffraction data on various nitrides are also given in (Table I).

TABLE I.

Composition	Symmetry	Type	Length of unit cell A	Density		Number of molecules in unit cell
				calc.	found	
BN	Not cubic	—	—	—	2·34	—
Si_3N_4	ditto	—	—	—	3·44	—
SeN	cubic (face centered)	NaCl	4·44	4·21	4·2	4
TiN	ditto	NaCl	4·40	4·81	5·18	4
VN	cubic (face centered)	NaCl	4·28	5·46	5·63	4
ZrN	ditto	NaCl	4·63	6·97	6·93	4
NbN	ditto	NaCl	4·41	8·26	8·4	4
TaN	ditto	NaCl	—	—	14·1	—

TABLE II.

Composition	Melting temperature °C	Temperature of evaporation	Specific Resistance	
			in molten state ($10^4\sigma$)	at room temperature ($10^4\sigma$)
BN	3000 u. press.	Sublimates	∞	∞
Si_3N_4	1900 u. press.	Sublimates	—	—
AlN	2200/4 atm.	Sublimates	—	—
Be_3N_2	2200	Sublimates at 1850°	—	—
TiN	2930	No sublimation up to melting point	3·4	1·3
ZrN	2930	ditto	3·2	1·6
VN	2050 appr.	Decomposes partly, no sublimation up to melting point	8·5	2·0
NbN	2050 appr.	ditto	4·5	2·0
TaN	2800 appr.		—	—
SeN	2650 appr.	No evaporation noticeable when melting	—	3·08

TABLE III.

	Ti	N	C	Fe	Mn	SiO_2	Al_2O_3	CaO	MgO
Specimen 1	52·05	10·13	5·4	3·9	0·18	5·7	5·05	0·44	1·68
" 2	61·04	6·36	Not determined	1·97	Not determined	2·81	14·88	Trace	0·27

The data given by Friedrich and Sittig tend to indicate definite compounds of nitrogen and titanium. Delinger[8] confirms this and gives the following lattice parameters of the compound TiN: $a = 4{\cdot}32$ A, $d = 3{\cdot}05$ A, $v = 20\,\frac{a\ t^3}{\text{atom.}}$ There is the possibility of obtaining mixtures of nitride-carbides or cyan-carbides in various proportions by nitration in the presence of carbon, as

* Vestnik Metallprom., 1938, pp. 54-62.

† By courtesy of the Research Department, Diamond Trading Co., Ltd., London, E.C.1, from which copies of the complete translation can be obtained.

1 J. Percy, *Die Metallurgie*, Vol. 1, 1898, p. 757.

2 Stead, Journ. Iron and Steel Inst., Vol. 97, 1918, p. 157.

3 Comstock, *Met. Chem. Eng.*, Vol. 12, 1914, p. 577.

4 D. J. Mendeleyev, *The Fundamentals of Chemistry*, Vol. 1, 1932, p. 37 and Vol. 2, p. 379 (in Russian).

5 Zhukov, *Communications of the Institute of Physicochemical Analysis*, Vol. 3, 1926, p. 14 (in Russian).

6 Ostroumov, *The Factory Laboratory* (periodical), No. 5, 1935, p. 506 (in Russian).

7 E. Friedrich, L. Sittig, *Zeitschr. f. anorg. all gem.* Chem., Vol. 143, 1925, p. 293-320.

8 Delinger, *Gitteraufbau metallischer Systeme*, Leipzig, 1935, p. 46.

reported by Weiss[9] and Kaiser, who obtained a composition of the formula $Ti_{10}C_2N_8$ from nitrated TiO_2 mixed with carbon.

Owing to considerable affinity of titanium both to nitrogen and carbon various nitrides can be obtained depending on composition of mixtures, on the gas used for nitration and on the temperature applied.

Experimental Part

Powdered titanium nitride was melted in a resistance furnace for temperatures up to 3,000° C, consisting of two carbon electrodes and a heating chamber.

Graphite electrodes lead through carbon contact rings connected to a transformer by copper bus-bars. The lower contact ring rests on a support with a hole for the electrode and protected by an outer quartz case. The space between case and an inner paper bush is filled with charcoal powder. The case is covered by a ring-shaped lid on which the upper contact ring rests.

Experiments showed that by fusing highly refractory materials (magnesium oxide, zirconium) a current of 300 amperes and 7 volts generated a temperature of 3,000° in 1½–2 minutes. Eventually a zirconium carbide crucible was chosen as refractory vessel. The charge of powdered titanium was melted in 1¾ minutes.

With increased time titanium nitride evaporated; after 3 minutes the crucible was empty and with continued heating the crucible itself began to melt. With the electrodes correctly fixed the electric arc melted the crucible and its contents; titanium nitride crystallised as small dendrites in the crucible mass. The first fused bars of titanium nitrides (from powdered titanium) were of yellow brass colour and of metallic lustre. Pores indicated the presence of gas and chemical analysis showed pollution by various oxides and carbon (Table III). Metallographic analysis showed that the fused mass consisted of small globules, of characteristic yellow brass colour, i.e. titanium nitride within a grey matrix, probably representing impurities.

For producing pure, high-percentage powder of titanium nitride special laboratory equipment was acquired, and chemically pure TiO_2 prepared for titration was used, where as the atmosphere was nitrogen, nitrogen with hydrogen, and ammonia.

The nitration of pure titanium dioxide did not lead to desired results, therefore, a mixture of titanium dioxide and activated carbon in weight proportion 2 : 1 was employed, and in another test a small quantity of carbon (coal) was added. The employed gases were carefully cleaned.

Later, instead of one vessel with pyrogallol an arrangement of four vessels in two pairs was used; during the first part of the process nitrogen passed through the first pair and later on through the second pair. The results were estimated by the quantity of nitrogen in the nitrated product (Tables IV, V, VI and I).

TABLE IV.—NITRATING WITH NITROGEN

No. of Specimen	Quantity TiO_2 g.	Quantity C g.	Apparatus made of	Conditions	No. of Operations	Content of nitrogen per cent.
5	3	1·5	iron	150° C—1 hour, increasing heat during 3 hours to 1200° C, keeping at 1200° C for 3 hours.	single	12
11	3	1·5	nickel	Same as above.	single	17·1
13	2	1·5	nickel	150° C—1 hour, increasing heat during 3 hours to 1250° C, keeping at 1200° C for 3 hours.	double	17·47
16	2·5	1·25	nickel	Same as above.	triple	17·47
22	5	2·5	porcelain	Same as above.	single	12·71

TABLE V.—NITRATING WITH AMMONIA

No. of Specimen	Quantity TiO_2 g.	Quantity C g.	Apparatus made of	Conditions	No. of Operations	Content of Nitrogen per cent.
7	4	—	iron	150° C—1 hour, increasing heat during 3 hours to 1230° C, keeping 3 hours at 1230° C.	single	0·76
6	3	1·5	iron	150° C—1 hour, increasing heat during 3 hours to 1230° C.	single	7·6
10	3	1·5	nickel	Same as above, but 3 hours at 1250° C.	single	13·06 s.g. 5·18 (G.P.Z.)
15	3	1·5	nickel	Same as above.	double	17·47
18	2	1	nickel	Same as above.	triple	17·61
23	2	1	porcelain	Same as above.	single	19·31

TABLE VI.

NITRATION WITH A MIXTURE OF NITROGEN AND HYDROGEN

No. of Specimen	Quantity TiO_2 g.	Quantity C g.	Apparatus made of	Conditions	No. of Operations	Content of Nitrogen per cent.
12	3	1·5	nickel	150° C—1 hour, increasing heat during 3 hours, keeping 3 hours at 1250° C.	single	16·4

Nitration without coal (No. 7) was not satisfactory, nor was that with ammonia and nitrogen. The results of ordinary single treatment were not always uniform; even a triple treatment did not show appreciable improvement; the test with specimen 23 could not be repeated.

The colours of the obtained nitrated product—from dark brown to golden yellow—were found to be lighter the more nitrogen the powder contained. Compared with known data the obtained product has a higher degree of nitration than those of other investigations. The Factory of Rare Elements made a product which contained 14·82% N[6], but the results of Friedrich and Sittig[7] were not achieved who obviously used a purer ammonia with the theoretically calculated amount of coal, whereas in our experiments an excess of 50% of dry coal was added.

The metallographic analysis of the fused product from powder No. 10 with 13·06% N shows already particles of titanium nitride and a few veins of grey colour representing the mass covered with slag of titanium dioxide which was not nitrated or rather represents the alloy[10] of Ti_2O_3 and TiO_2.

The crystalline titanium nitride easily scratches quartz, cuts glass, and trues emery grinding wheels at low peripheral speeds, generating sparks, but wears rapidly at high speeds. When truing grinding wheels N 46 at a peripheral speed of 5,200 ft./min. and a depth of cut of 0·0012 in. sparking ceased after truing of half the width of the grinding wheel, whereas a diamond passes over the whole width of 6 in. and wears only 0·004 in. Under such difficult conditions diamond becomes blunted by emery grinding wheels and cannot be used for more than 7 to 8 truing operations.

In spite of great hardness titanium nitride is not brittle, as it is difficult to obtain a fine powder from the fused

9 L. Weiss, P. Kaiser, *Zeitschr. f. anory. all gem.* Chem., Vol. 65, 1910, pp. 345-402.

10 E. Junker, *Zeitschr. f. anorg. all gem.* Chem., Vol. 228, 1936, pp. 97-111.

11 K. Becker, *Hochschmelzende Haristoffe.* ("Refractory hard materials and their use in industry"), ONTA, 1936. (In Russian, obviously translated from the German edition).

product which is very resistant to the blow-like action of the grinding wheel. It withstood temperature changes well, for instance when molten copper was poured over it, although the product was far from homogeneous. The fused products of high percentage powder (specimen 23) were not tested.

TABLE VII.

COMBINED NITRATION; AFTER PRELIMINARY OPERATIONS, TABLES IV, V, VI, BUT WITH AMMONIA

No. of Specimen	10	12	16
Nitrogen contents % after single operation	16·19	17·75	16·90

Quantity of TiO_2 and C. see Table V.
Apparatus made of porcelain.
Conditions: 1 hour at 150 deg. C., increasing temperature during 1 hour, keeping temperature for 3 hours at 1,250 deg. C.

For obtaining crystalline titanium nitride from the metallic melt a high-frequency furnace of the laboratory I.G.P.Z., originally built for a temperature of 2,000 deg., was adapted. A graphite cylinder with zirconium lining, inside a quartz casing was provided and a nitrogen atmosphere was applied to prevent oxidation. With this furnace a small cylinder of 50 mm. length and 10 mm. diameter was made. The specimen contains dust, obviously caused by particles of slag having separated from the dough-like mass of nitrides or by separation in gaseous state. Crystals of titanium nitride from molten metal were also made, for which a graphite crucible with zirconium lining was used and a mixture of spongy iron, powdered titanium nitride and 20% FeTi (calculated to obtain 2–3% Ti in the melt); the total weight was 200–250 gram. The mixture was melted again in nitrogen atmosphere under nitride slag.

Superheating temperatures of 1,600,° 1,800,° 2,000,° 2,200,° and 2,400° C. with slow and rapid cooling were used. The full programme could not be carried out owing to the difficulties in measuring high temperatures and on account of evaporation of metal and forming of cyanide compounds. Further, it was impossible to slow down the cooling due to mixing of metal with slag. The growth of crystals, however, requires that the molten metal should be kept unmoved. The following tests were carried out at the given temperatures—without corrections: 1st melt (sponge) 1,460°–1,480°, 2nd melt (sponge) 1,600°–1,650°, 3rd melt (sponge) 1,800°–2,000°, and 4th melt (ball-bearing steel) 1,800°–2,000° C. The analysis of the basic materials is given in Table IX. When the stated temperatures were reached the current was switched off and the metal allowed quietly to cool down. Nitride crystals rose from the bottom and were found in the upper parts of the small bars both as small single crystals and as complicated twin forms.

The micro-structure of iron and ball-bearing steel in corroded state shows a not very usual form of the structural components of mild iron in which the separation of a peculiar eutectic has no connection with pearlite grains. Crystals of the hard component of the eutectic are found both in the pearlite and in the ferrite zones.

A photo-micrograph showed dark lines which are shadows due to thin flakes of blue colour, probably titanium carbo-nitrides; similar separations of a very limited extent are to be found in ball-bearing steel remelted under a mitride slag, whereas cubic crystals of titanium nitride are more frequently found. Although the structure of carbo-nitride eutectics was not found in both the non-etched corroded and the etched metallographic specimens, the structure of dendrites in this steel suggested their presence.

Of some interest are the properties of iron containing about 2% of titanium and molten under a nitride slag in nitrogen atmosphere with cyanide (the latter being formed by the reaction of nitrogen with incandescent carbon of the crucible).

In spite of the comparatively small hardness (Brinell 180 kg./sq. mm., load 750 kg.), the bar could not be machined with a high-speed steel milling cutter, and a corundrum grinding disc had to be used instead. No further mechanical tests were made. The maximum size of the single crystals of titanium nitride in the fused products was about 0·05 mm., crystal formations up to 3 mm. in size were found at the surface in contact with the slag; these, however, were conglomerates and not single crystals.

The growth of large crystals in the melt requires slow and undisturbed cooling and a reduction of the specific gravity by adding light metals. [It seems essential for the growth of large crystals that crystallisation starts from one point and not from many points simultaneously. —Ed.]

Technical Uses and Construction

The considerable wear of fused crystalline titanium nitride when used for truing grinding wheels at high peripheral speeds and the easy truing of stationary grinding wheels suggest that the substitution of diamond by titanium nitrides is only possible when the truing arrangements are altered. Therefore, rotary wheel truing devices were developed. No technical difficulties exist in making these discs from powdered titanium nitride and in driving the device with the necessary speeds. [This suggests a positive rotary drive of the discs.—Ed.]

The conclusions are based on the absolute hardness scale of Hertz and Auerbach which shows great differences between corundum and diamond. With abrasion hardness (Tula-Rosiwal; relative hardness of corundum 1,000) diamond ranges up to 140,000, whereas sintered carbide (Widia) is between 2,000 and 30,000. The latter scratches corundum, but is not scratched by it—it is easily scratched and cut, however, by diamond.[11] Titanium nitride is in a similar category, its hardness being 8 to 9 on Mohs' scale. Crystalline titanium may also be of interest as an addition to abrasives for fine grinding.

Conclusion

1. The production of crystalline titanium nitride by melting powdered material can be considered as solved, both by the method of passing electric current[7] through pressed bars or by a metallurgical method which permits any desired shapes and masses of the crystalline titanium nitride to be formed.

2. The use of fused titanium nitride for truing grinding wheels is possible owing to its great toughness and hardness, but alterations of the truing equipment are required.

3. The use for cutting glass as substitute for diamond.

4. Iron, steel, and cast-iron found in the melt under the nitride slag show peculiar structure and properties which should be of great interest, but further investigations in this direction are required.

Fridman's Theory of Strength of Materials

By G. Stanley Smith, B.Sc., A.R.I.C.

By the courtesy of Prof. S. Kishkin, the assistant director of the U.S.S.R. Aircraft Materials Research Institute, we have reeeived a copy of Dr. Jacob Fridman's book on "General Theory of Strength and Diagram of Mechanical State," recently published by that Institute. The difficulties in reviewing work of this character from the Russian will be appreciated; in the present instance, however, the fact that several papers, to which Dr. Fridman refers, and which are not available in this country, increase the difficulties. These pages apparently contain much of the experimented data upon which the diagrams are based and the author assumes that the reader will be able to consult them. However, in view of the attention now being given to the assessment of strength of materials, it is believed that the theory expounded by Dr. Fridman will have more than ordinary interest.

ONE of the most important practical problems of science and one which enters into nearly every branch of human activity is the meaning and correct evaluation of the strength of materials. This is by no means a new problem since over a period to be reckoned in centuries it has engaged the attention of many of the greatest thinkers. At the present time, with the increase of knowledge acquired by research in various fields and the use of instruments and methods unknown to the earlier workers, certain general laws governing the behaviour of a material subjected to stress can be formulated with a fair degree of precision and we now have a much clearer idea of the internal structure and composition of all materials. Nevertheless, many of the fundamental questions have not received a final answer. Indeed, it has frequently happened that increase of knowledge has introduced difficulties and apparent contradictions which have had the effect of causing the goal to recede at a rate greater than our rate of progress towards it. In the matter of the ability of a material to resist forces tending to deform or break it, some of the most common processes are not properly understood. Theories have not been lacking but it is safe to say that not one is generally accepted as proved, whilst modifications and improvements are constantly appearing. A careful consideration of the various strength theories which have been advanced indicates that their application must be limited to a restricted field or that, at best, they are only approximate representations of observed behaviour.

The study of strength is complicated by the fact that methods of testing designed to assess a specific property have been merely empirical and unrecognised as such by the investigator. Thus, in the case of "tensile strength," calculations of stresses have been made, and still are for most practical purposes, by relating the load at all times to the original cross-sectional area. The result refers only to a specimen of the shape and size of that tested and considerable variations could be obtained by altering the form of the test-piece. Again, "ductility" may be assessed from the elongation or the reduction in area of a tensile-test specimen but the two methods of assessment may contradict one another when it comes to considering if one material is more ductile than another.

The empirical nature of some of the physical tests carried out in the laboratory and the lack of correspondence of the results obtained with the sort of failures which occur in practice have been stressed by many authors; for instance, Schuster[1], in his review of the relationship between the results of mechanical tests and service failures, came to the conclusion that these tests had little use other than to check that a material conformed with the specified requirements—they could not be used for judging if one material was superior to another nor for any true assessment of the behaviour of parts made from the same material as that tested.

The term strength or resistance to destructive forces has had to be defined differently in relation to each of the tests carried out to estimate it and, as a consequence, we have to talk about the strength under conditions of tension, compression, torsion, bending, indentation, fatigue, wear and creep as so many different entities. Quantitative connections between certain of these tests have been traced but no general theory of strength relating them all has yet come into favour. It appears, therefore, of considerable interest to examine a theory, put forward recently on the basis of much experimental work by the Russian author Ya. B. Fridman,[2] which claims to unite the various theories of strength by revolving their apparent contradictions and to provide the possibility of indicating on a single diagram all the possible stress states of a material, including those which would arise under fresh testing conditions which may be developed in the future. Many aspects of the unified theory are acknowledged by the author as requiring investigation by means of specially designed experiments before they can be regarded as fully proved and the "diagrams of mechanical state," though based upon the best available data, are expected to be made more accurate in their representation of physical properties as research, instigated by the theory, proceeds.

In the present article, following a short résumé of some of the earlier theories which are relevant to an understanding of the views put forward, an attempt is made to give an account of Fridman's theory and diagrams.

Theories of strength appear to have originated with the desire of the mechanical engineer to discover how he could relate the behaviour of a material under the complicated stresses encountered in practice with the behaviour of the material under some simple stress, such as uni-axial tension. The development of such theories and the consequent accumulation of data indicated, after a while, that even the simple stresses

1 L. W. Schuster, *Engineer*, 1941, CLXXI, 389.
2 Ya. B. Fridman, "A Unified Theory of the Strength of Materials," (Moscow, 1943—in Russian).

were not always what they seemed to be—that, for instance, a so-called tensile failure was often a shear failure. Furthermore, these theories were developed from the ideas of the theory of elasticity which was not intended to cover plastic materials and materials stressed above the elastic limit. This fact does not, of course, invalidate the conclusions of all such theories in connection with plastic behaviour but it is necessary to realise that certain of them are restricted to elastic behaviour where stress is proportional to strain.

The theory of maximum stress, visualising the applied stress as being compounded of three stresses in mutually perpendicular planes, supposed that these component or principal stresses were completely independent of one another and that, therefore, the material would fail when one of them reached the value at which the material would fail in a simple tensile test.

The plane on which the maximum stress acts is not the plane showing the greatest strain. The maximum strain theory supposed that failure occurred when the maximum strain reached the value of the strain at the point of failure in a simple tensile test. In both these theories the yield-point represented the point of failure.

The maximum shear theory assumed that failure occurs along certain planes, by sliding, and not in a direction perpendicular to them. It supposed that a failure occurred, under combined stresses, when the maximum shear stress became equal to that at failure in a simple tensile test where the equivalent shear stress is to be taken as one half the tensile stress.

The maximum strain energy theory supposed that failure occurred when the energy absorbed per unit volume at any point equalled the energy absorbed per unit volume at failure in a simple tensile test. An alternative method of stating this theory gives the condition for failure (yielding) as the attainment of equality between the sum of the squares of the differences of the principal stresses, taken in pairs, and twice the square of the yield-point in the tensile test.

There are other theories of strength which are, in general, modifications of these main theories. In Fridman's treatment the stress, strain, shear and strain energy theories are regarded as typical and are referred to as the first, second, third and fourth theories respectively.

The strength of a material is, broadly speaking, a question of deformation under load. Under the conception of deformation there have to be considered the elastic and plastic changes of form suffered by the material and the transitions from one stage of deformation to another, including the final transition in which destruction or failure occurs. Neglecting for the time being the fact that elastic and plastic changes may be taking place at the same time, and representing elastic deformation by E, plastic deformation by P and failure by F, one may symbolise the critical or limiting states of materials under load as $E \rightarrow P$, $P \rightarrow F$ and $E \rightarrow F$. A knowledge of the conditions under which these transitions take place—the main problem of the theory of strength of materials—is of the utmost importance in three branches of technology, viz.: (1) The design of structures subject to static, dynamic, repeated and alternating loads, etc. (2) The treatment of metals by pressure, including rolling, pressing, forging and drawing. (3) The treatment of metals by cutting, where machinability, wear of tools and deformation of the work have to be considered. For (1) it is necessary to avoid the total transition $E \rightarrow P$ and, of course, the transition $P \rightarrow F$ (or $E \rightarrow F$ in the case of brittle material); for (2) $E \rightarrow P$ has to be facilitated and $P \rightarrow F$ avoided, and for (3) $P \rightarrow F$ (or $E \rightarrow F$) has to be facilitated.

Elastic Deformation

The elasticity of a material is characterised by Hooke's Law, the proportionality of stress and strain, and by Poisson's Ratio, the proportionality of transverse and longitudinal strain.

In the elementary theory of elasticity it is assumed that the resultant of all the stresses over any given section of a body in equilibrium must neutralise all the external forces acting over the section. A state of strain caused by the application of an external force induces stresses which tend to neutralise the external force. This idea led directly to the first theory of strength.

Whilst the "section method," whereby the stress on a section is computed as the resultant of the stresses which balance the external force, may give the true picture in certain cases, it is inadequate in others, according to Fridman, because it fails to reveal stresses that are undoubtedly present. One such case is to be found in the behaviour of a brittle material under compression. Here fracture occurs more or less in a line with the applied force where tensile stresses would not be revealed by the "section method." In fact the general case, covered quantitatively by Poisson's ratio, of the existence of transverse strains without transverse stresses to correspond appears obscure when considered from the point of view of the "section method."

Three methods of overcoming this difficulty have been put forward. Mesnager attempted to account for longitudinal fracture on the basis of the presence of internal heterogeneities (caverns) which acted as notches and so created transverse stresses. It is not a satisfactory explanation, apart from the fact that it does not deal with the nature of transverse elastic strain, since it is unlikely that the same sort of heterogeneities exist and exert the same sort of influence in materials so different in composition as glass, stone, plastics, metals, etc. The second attempt at explanation was derived from the maximum strain theory; failure under compression occurred not from stresses but from strains. In this case, although the physical picture of failure received little clarification, calculations based upon it agreed well with experimental results for the failure, under different stress conditions, of brittle materials. The third method, suggested by Kirpichev in 1900 to explain Poisson's ratio and used by the geologist Schmidt in his studies of the compression of minerals, employs the idea of a jointed rhomb (Fig. 1), in which the vertices represent four neighbouring atoms.

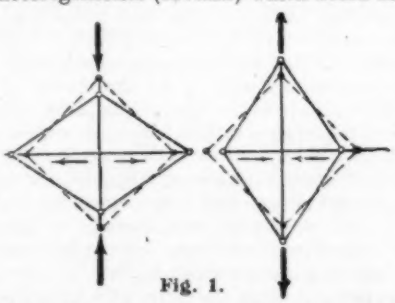


Fig. 1.

The conception of the jointed rhomb did not come into favour but Fridman has now shown how it may be used to accommodate the first and second theories of strength in one scheme. It is considered that the reason

for the failure of the "section method" to reveal the stresses over a section when deformation indicates their presence, must be found in the balancing of internal forces deforming the body not with the external forces, as normally supposed, but with other, similar, internal forces of opposite sign. This point is illustrated by means of Figs. 2 and 3.

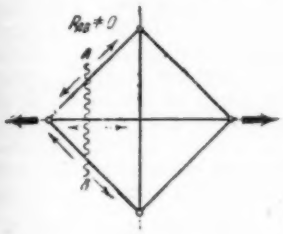


Fig. 2.

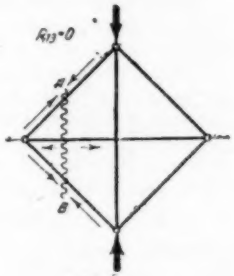


Fig. 3.

In Fig. 2 each of the three connecting links which pass through the section AB is in tension. These internal forces give a resultant and the "section method" is, therefore applicable. Equilibrium is established between external and internal forces causing deformation.

In Fig. 3 the vertical external compressing forces produce compressions in the inclined elements and tensions in the horizontal. As a result of deformation these forces are mutually balanced without the application of an external force in the horizontal direction. Consequently when we take the vertical section AB there is no resultant and we fail to find any external transverse forces. If we wish to discover these transverse forces we may do so by preventing the deformation, for example, by fixing a ring around a cylinder which is being compressed. The tension in the ring takes the place of the tension in the transverse connecting links of the rhombs.

The evaluation of the internal (inter-atomic) forces corresponding with the transverse elastic deformation and the longitudinal rupture in compression must necessarily be a subject for special investigation. For the purpose of the present discussion it is merely necessary to indicate that such forces exist and that they do not require any special hypothesis, such as that of Mesnager. The treatment is considered to justify the use of the second theory of strength—the maximum strain theory—which, previously, had no physical basis. It introduces the idea of "induced stresses" as an alternative to transverse strains. The first and second theories may, therefore, be brought together as a single "theory of maximum tensile forces" insofar as failure of an elastic body through rupture is concerned if calculations are based upon "induced stresses."

Tangential stresses which are caused by plastic deformation and shear should not be altered because of the presence of the internal transverse forces. Therefore, maximum shear stresses, τ_{max}, determined by means of the formula $\tau_{max} = \frac{\sigma_{max} - \sigma_{min}}{2}$, may be calculated by the usual methods.

The following symbols are used in the further development of the theory :—

$+\sigma_{max}$ . . the max. external normal tensile stress.

$-\sigma_{max}$ . . the max. external normal compression stress

S . . . . the true normal stress related to the cross-sectional area at a given moment of the deformation.

τ . . . . the maximum external tangential (shear) stress.

t . . . . the true tangential stress related to the cross-sectional area at a given moment of the deformation.

σ_s and S_s . . the yield-points corresponding with the transition, E → P, σ_s being expressed as normal and S_s as true normal stress ($\sigma_s = S_s$ approximately, with small deformations).

τ_s and t_s . . the tangential stresses corresponding with σ_s and S_s ($\tau_s = t_s$ approximately, with small deformations).

σ_B . . . . . the ultimate (conventional) stress.

S_B . . . . . as σ_B, but expressed in true stresses.

t_B . . . . . as σ_B, but expressed in true tangential stresses, $t_B = \frac{1}{2} S_B$.

S_k . . . . . the true normal stress at failure, if the type of failure (rupture or shear) is not defined. It corresponds with the transition, P → F or E → F.

t_k . . . . . the resistance to shear in failure from tangential stresses.

S_T . . . . . the resistance to rupture in failure from normal tensile stresses.

D . . . . . the modulus of plasticity or the coefficient of strengthening (strain-hardening) in the plastic region determined from the slope of the curve (t, γ).

δ_k . . . . . the plasticity, or the maximum residual relative elongation which a material sustains before failure.

e . . . . . the true elongation, referred to the length at a given moment of the deformation.

$$e = \int_{l_o}^{l_k} \frac{dl}{l} = \log \frac{l_k}{l_o}$$

γ . . . . . relative (plastic) displacmeent.

μ . . . . . Poisson's ratio.

E, G, K . . the elastic moduli.

The Transition from Elastic to Plastic Deformation

In general, the transition E → P is represented on the stress-strain curve not by a single point (as with P → F or E → F) but by a range and the selection of a definite point is somewhat arbitrary. The yield-point is measured, therefore, by fixing a definite but small value for the residual elongation.

The plastic deformation of mono-crystals of metals appears to be conditioned solely by the maximum shear stresses and the third theory of strength should be applicable. Poly-crystalline metals and alloys used in industry behave in a more complex manner. It is found, for instance, that the yield-point in torsion is normally more than half the yield-point in tension. The results obtained for plain-carbon steels were :—

TABLE I

% C	σ_s	$\frac{1}{2}\sigma_s$	τ_s
0·12	22	11	14
0·35	31	15·5	19
0·66	42	21	26

The fourth theory of strength gives results in closer agreement with the experimental. It assumes that the criterion for the transition, E → P, is not the stresses but the energy of elastic deformation. Ros and Eichinger showed in 1929 that the fourth theory may be treated as a variation of the third theory. The energy of change of form is connected with the differences of the principal stresses and therefore, with the maximum shear stresses. The recent work of Davidenkov,[3] of Mirolyubov[4] and of Oding[5] indicates that the non-correspondence of τ and $\frac{1}{2}\sigma_s$ may be explained on the basis of the incorrect use of the theory of elasticity for calculating stresses in a body which has already begun to suffer some plastic deformation. Oding goes on to say " for explaining the inequality, $\tau_s > 0{\cdot}5\sigma_s$, ... it is unnecessary to have recourse to the theory of strength which is based upon a consideration of the potential energy of deformation. For plastic materials the theory of maximum shear stresses is in agreement with the results of experiments provided the yield-point in torsion is calculated in accordance with the true curve of stress distribution (or more correctly, in accordance with the approximate curve without taking the strengthening into account)."

Thus, there is no need for the fourth theory of strength and the third theory is adequate to deal with the transition E → P. Calculations of shear stresses under various conditions of stress which have been made by Fridman on the basis of the third theory and the use of true stresses proved that the yield-points of a material under all conditions had the same values. (See Table II).

Plastic Deformation

Plastic deformation after the transition at the yield-point is also conditioned by shear stresses. Cross-calculations may be made, such as tensile strength to Brinell hardness number and vice versa. In fact, knowing the true shear stresses one can determine approximately the true residual deformation corresponding with the stress in any stress state beyond the yield-point. This is made possible by the fact that the curve relating the true shear stresses with the true residual deformations—the generalised curve of displacement, called " the generalised flow-curve " by Ludwik—appears to be a characteristic of a material at a given temperature and speed of testing.

The Conditions of Failure

If a material be restrained laterally it will resist any compression force, however large. Compression alone can never be the cause of failure. There remain, therefore, the two possibilities for the cause of failure—tension and shear.

Until recently it was supposed that every material, at a given temperature, speed of deformation, etc., possessed *one* resistance to failure which was usually called the resistance to rupture or fracture. Davidenkov[6] in 1936 proved that every material had two physically different resistances to failure which he called the brittle strength and the viscous strength respectively. These he connected with normal stresses. Fridman has developed the idea further and states that every material has a resistance to rupture, S_T, and a resistance to shear, t_k, which, in general, differ in physical nature and magnitude. He connects S_T with normal stresses and t_k with tangential stresses. All failures of " ductile " materials are referred to tangential or shear stresses even in the case of failure under tension. But by calling a material " ductile " nothing more must be meant than that the material behaves in a certain way under certain conditions. Under other conditions the material may be " brittle."

That every material has two possible methods of failure enables Fridman to explain certain difficulties, of which three may be mentioned.—(1) The strengthening effect of a notch on a tensile test specimen. On the supposition that the tensile failure was caused by normal stresses the stress concentration at the notch should lower the apparent strength of the material. In actual fact, the strength, in the case of most metals, is raised. The effect may be explained by considering the failure in a tensile test as being brought about by shearing stresses. Since $\tau_{max} = \frac{\sigma_{max} - \sigma_{min}}{2}$ it follows that τ_{max} falls with an increase in σ_{min}, indicating that shear stresses are lowered with bulk tension and that the strength of a notched sample, measured in tensile stresses, appears high. (2) In a number of cases (zinc and its alloys, coarse-grained steels, etc.) the strength under dynamic testing is low whilst the material possesses high static ductility and plasticity. The reason lies in the two-fold character of failure. With rapid application of load, particularly at low temperatures and when the sample is notched, the failure is due to rupture (normal stresses). The dynamic tests reveal that zinc and coarse-grained steels have a low resistance to rupture (S_T). Under static conditions failure occurs by the overcoming of the resistance to shear, (which is considerably more than the yield-point). (3) Navier attempted to discover the influence of stresses in mutually perpendicular directions by means of hollow spheres which were made to fracture by pumping water into them. The results showed that the addition of a second tension stress did not raise the danger of failure over that with uni-axial tension.

Navier concluded that he had confirmed the first theory of strength and his conclusion would have been correct if failure had occurred from rupture. There is, however, no doubt that the failure was a shear failure. Actually he was checking the third theory of strength and his results merely mean that τ_{max} was unchanged. If Navier's spheres had been made of glass or other material which fails in tension from rupture, instead of iron and copper, the influence of a second tensile stress would have been studied in a manner capable of exposing it.

Failure from Normal Stresses (Rupture)

In nearly all states of stress—except that of compression from all sides—there arise in the body which is being deformed tension stresses as well as compression and tangential stresses. The reason that most metals do not rupture is that the resistance to shear, t_k, is much less than the resistance to rupture, S_T. The shear stresses attain the yield-point and the failure (shearing) stress before the tension stresses can attain the failure (normal) stress, i.e., $t_k \leqslant S_T$. On the other hand, the so-called brittle materials have $S_T \leqslant t_k$ and they are subject to shear failure only in stress states where the ratio $\frac{\tau_{max}}{+\sigma_{max}}$ is very large, for example, in indentation.

3 N. N. Davidenkov, *Zavod. Lab.*, 1938, **7**, 328 (in Russian).
4 I. N. Mirolyubov, *Zavod. Lab.*, 1938, **7**, 458 (in Russian).
5 L. A. Oding, *Zavod. Lab.*, 1938, **7**, 443 (in Russian).
6 N. N. Davidenkov, " Dynamic Testing of Metals," 1936 (in Russian).

For mono-crystals which fail by rupture in linear tension (zinc, alpha-iron, sodium chloride etc.) the decisive factor appears to be the critical value of the normal tensile stress on the crystallographic planes.

In the case of plastic metals it would be possible to observe rupture only in stress states where the ratio $\frac{\tau_{max}}{+\sigma_{max}}$ is very small e.g., with tension of equal value on all sides. Experiments on alloys of Pb, Al, Cu, Ni, austenitic steels, etc., have so far been unsuccessful in demonstrating the occurrence of rupture.

This form of failure in metals is known in two cases only.—(1) Fracture of cold-short metals (alpha-iron, zinc) under conditions of low temperature, dynamic loading, etc. which cause $\frac{\tau_{max}}{+\sigma_{max}}$ to be low or $\frac{t_k}{S_T}$ to be high. A shining ("crystalline") fracture is characteristic. (2) Inter-crystalline fracture where the grain-boundaries are weakened by inclusions, impurities, etc. Cold-shortness is clearly revealed.

It appears, therefore, that the practical significance of the resistance to rupture of a metal or an alloy is not very great. Fridman points out that this property has been much over-estimated by all previous workers.

Failure from Tangential Stresses (Shear)

As indicated above, failure in the majority of metals in various stress states is considered to take place from shear stresses. Justification for this contention is provided through a comparison of the true shear stresses at the point of failure in tension, compression, shear, torsion and bend. It is found (see Table 2) that results obtained in the various tests are in close agreement—for any given alloy—when they are calculated in true shear stresses. Hence, knowing, for example, the resistance to shear, it is possible to calculate the resistance to compression, to tension, to torsion, etc.

Although the calculation of stresses has not yet been carried out for certain complicated stress states there appears to be no reason for supposing that any difference in principle would be involved. Failure in wear, cutting of metals, creep and failure should be referrable to the constants for a given material, resistance to rupture, S_T, and resistance to shear, t_k.

Thus, Davidenkov has proved that the scratch hardness is determined by the resistance to viscous failure (shear).

In cutting, a comparison of different types of drillings, millings etc., indicates that there are cases both of rupture failure and of shear failure.

When creep tests are carried to the destruction of the sample failures occur most frequently from inter-crystalline rupture.

Fatigue is probably the most complex case. There is, however, reason for supposing that fatigue is closely connected with the material's resistance to shear. Both Gough[7] and Mailänder[8] observed that a steel which possessed a low impact value on account of temper brittleness had exactly the same fatigue value as a steel with a high impact value. In connection with the observed "brittle" fracture in the fatigue failure, Davidenkov[4] writes: "In spite of the apparent similarity, the brittle fracture of fatigue has a physical nature different from that of the brittle fracture of single shock: the absence of deformation is only a semblance for, in actuality, there have been numerous opposing deformations. Therefore in a failure from fatigue there is to be found a reflection of the viscous strength and not the brittle strength of the metal." Finally, it may be noted that the connection between the fatigue limits in tension-compression, σ_{w_2}, in bend, σ_{wb}, and in torsion, τ_w, may be expressed by the equations, $\sigma_{wb} = 0{\cdot}95\ \sigma_{w_2}$, and $\tau_w \approx 0{\cdot}6\ \sigma_{w_2}$ which closely correspond with the fourth and the third theories of strength.

7 Gough, "Fatigue of Metals," 1935 (in Russian).
8 Mailänder, *Stahl und Eisen*, 1935, **55**, 39.

TABLE II

RESISTANCE TO SHEAR FAILURE, t_k, FOR VARIOUS MATERIALS CALCULATED AS TRUE SHEAR STRESSES IN *kg./mm.²*

	Tension $S_k/2$	Compression	Torsion $W=\frac{\pi d^3}{12}$	Shear	Bend $W=\frac{bh^2}{4}$
Duralumin (rolled)	29·4	29·0	28·0	27·7	27·3
Al alloy (Cu 4%, Si 2%) ..	23·8	28·2	26·0	25·3	22·5
Mg alloy, MA4, Cast.. ..	—	13·2	—	14·5	—
Mg alloy, Mg II, Wrought ..	10·7	10·5	9·6	9·9	—
Brass	38·5	31·1	—	31·3	—
Bronze	46·2	46·8	—	47·0	—

The Unified Theory of Strength and the Diagram of Mechanical State.

A theory of strength which sets out to explain the limiting states and make their calculation possible, ought to take into account the possibility of each of the three different transitions, E → P, E → F and P → F, for any stress state. Hitherto, diagrams and schemes proposed for the explanation of brittle and plastic conditions have not given a picture of the stress states (Ioffe, Ludwik, Kuntze, Thum and Federn, Mailänder, Davidenkov) and those which took into account the different forms of stress state, such as Mohr's circle, have not been applicable to the analysis of the type of failure. Fridman, on the basis of the arguments summarised above, presents a single theory of strength, designed to fulfil the necessary conditions, which is suitable for expressing all the critical transitions of the most varied materials and for giving a graphical picture of practical value for the registration of any stress state on one type of diagram.

Every stress state is characterised by a definite relationship between the three stresses, $+\sigma_{max}$, $-\sigma_{max}$ and τ_{max}. It can, therefore, be represented as a straight line in the three-dimensional system of co-ordinates shown in Fig. 4. This system is not well-adapted for practical use and, since the projections of such lines on the three planar axes of co-ordinates give all the information required, Fridman uses the planar diagram shown in Fig. 5. Three only of the four quadrants are required. Their axes are

(1) $+\sigma_{max}$, τ_{max}
(2) τ_{max}, $-\sigma_{max}$
(3) $-\sigma_{max}$, $+\sigma_{max}$

Any stress state may be depicted by means of a line (or lines, in more than one quadrant) of a definite slope which is the same, whatever the material. Any fresh state of stress can always be represented on the diagram provided only that the ratios of the maximum stresses are capable of determination.

A property of a material which could be found to be independent of the stress state would be represented on the three-dimensional diagram by means of a plane parallel with the appropriate planar axis of co-ordinates (Fig. 4) and therefore by straight lines parallel with the

axes on the planar diagram. There are, as indicated by Fridman, three such properties :

(1) the yield-point, t_s, expressed in true shear stresses.

(2) the resistance to shear, t_k, expressed in true shear stresses.

(3) the resistance to rupture, S_T, expressed in true normal stresses.

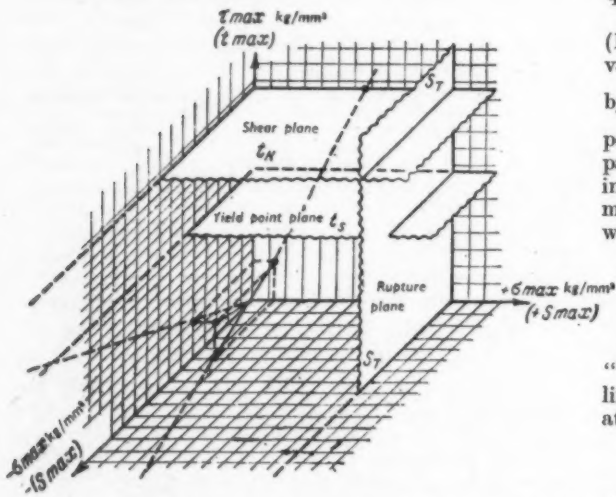


Fig. 4.—Spatial diagram of mechanical state. The projections on the three planes ($+\sigma_{max}$, τ_{max}), ($\tau_{max}-\sigma_{max}$) and ($-\sigma_{max}$, $+\sigma_{max}$) indicate the ratios between two of the possible three kinds of stress. The figure illustrates compression with reference to the transverse inter-atomic forces.

of plasticity, coefficient of strengthening or the work-hardening effect may be calculated. It is claimed that the scheme is a great improvement on all previous schemes since it is not merely a better representation of the behaviour of a material in a qualitative sense, but it is actually a method characterising quantitatively the mechanical state of a material in a way similar to that by which the constitutional diagram characterises quantitatively the phase state of an alloy.

The diagram is useful for the following purposes :

(1) The characterisation of any stress state by one value—the angle of inclination of a straight line, i.e., by the ratios, $\frac{\tau_{max}}{+\sigma_{max}}, \frac{\tau_{max}}{-\sigma_{max}}$ etc. By this means it is possible to use the one system for measuring and comparing numerous complex stress states in machine parts, in pressure and cutting treatment and even those which may be the subject of study in geology and other sciences where the laws of deformation of a solid body are of interest. Naturally, special investigations will have to be carried out to determine the precise values of the angles of inclination of lines representing the more complex states of stress.

(2) The characterisation on the one diagram of all three "limiting states" of a given material by means of three lines, plotted on the basis of experimental determinations of the characteristics :

The yield-point, t_s, determined, for example, from a tensile test ($\frac{1}{2}\sigma_s$) the resistance to shear, t_k, determined in a shear, torsion or compression test.

The resistance to rupture, S_T, determined in the case of brittle materials in a tensile test.

(3) The direct determination from the diagram of the strength and the plasticity of a material in any stress state when the basic properties, t_s, t_k and S_T, are known.

(4) The construction of complete deformation curves for materials which are brittle in tension by changing the stress state (from tension to torsion or from torsion to compression).

(5) The determination from the diagram of the influence of the stress state upon the type of failure and, in particular, the determination in which critical stress state there occurs a transition from one type of failure to another.

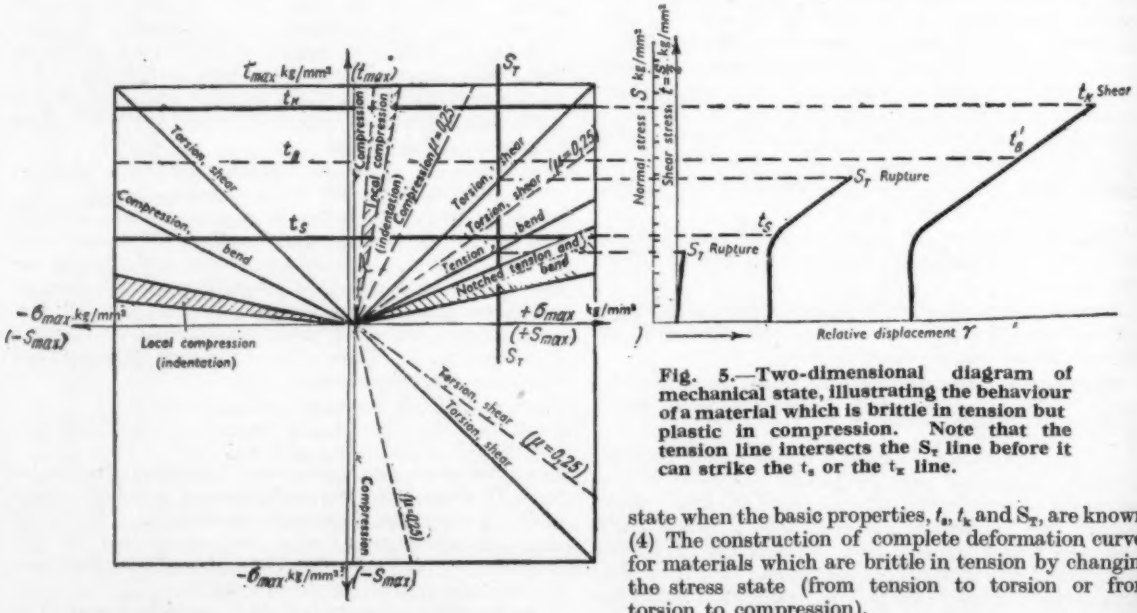


Fig. 5.—Two-dimensional diagram of mechanical state, illustrating the behaviour of a material which is brittle in tension but plastic in compression. Note that the tension line intersects the S_T line before it can strike the t_s or the t_K line.

The complete diagram of mechanical state consists of the diagram referred to above and a true stress-true strain curve (Fig. 5). The plastic deformation with a given shear stress can be determined and the modulus

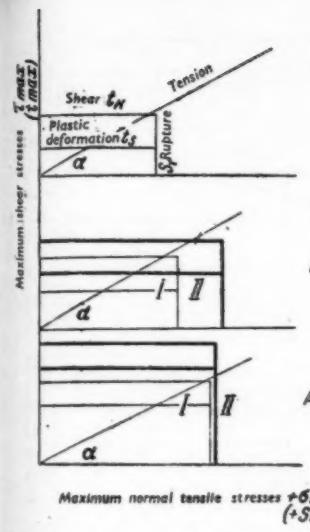
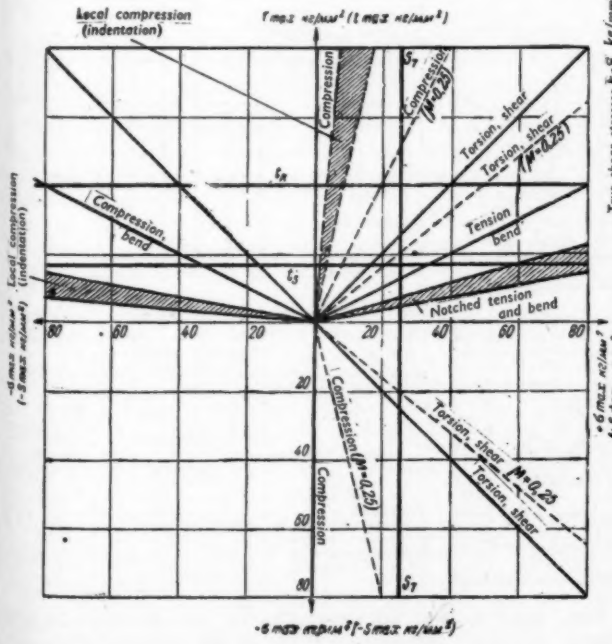


Fig. 6.—Transition from one type of failure (rupture) to another (shear) with change in the values of t_s, t_K and S_T. In case B the viscous character is preserved in the change I–II, but in case A it is changed from viscous to brittle, shear to rupture.

(6) The determination of the significance of alterations of the conditions of deformation by plotting on the same diagram the effect of altering the temperature, the speed of deformation, etc. (Fig. 6.)

(7) The possibility of simplifying the study of fatigue, creep, wear resistance, etc.



Examples of Fridman's Diagrams of Mechanical State

In the case of most plastic metals, such as aluminium, copper and magnesium alloys and steels subjected to pressure treatment, the resistance to rupture, S_T, has not yet been determined. Consequently the S_T line is omitted in such cases.

Those lines of stress state which are determined from the transverse inter-atomic forces (or "induced stresses" calculated by means of the second theory of strength) are plotted as dotted lines and μ is assumed to have the value, 0·25.

The stress-strain curves—the generalised curves of displacement—are obtained by means of tensile tests in the case of plastic materials and by means of torsion or compression tests in the case of more brittle materials. (Figs. 7, 8, 9 and 10.)

Fridman has put forward his theory and diagrams, which are admittedly incomplete and approximate, as a basis for further study. One of the main problems is concerned with stress distribution and the behaviour of complex parts.

The laws indicated in the previous pages can be established only for true stresses. In practice, distribution of stress is non-uniform and the coefficient of concentration which relates the maximum stress to the mean refers only to a sample of given form and sometimes to one of given dimensions. It has, therefore, been suggested that the conventional stress is of greater value than the true stress. Nevertheless, the ultimate tensile stress is rarely proportional and sometimes unrelated to the forces causing a body to yield or to fail. It is, of course, these forces and not the stresses which are of practical importance. A general solution to the problem of determining the maximum true normal and shear stresses when the external forces are known has yet to be found.

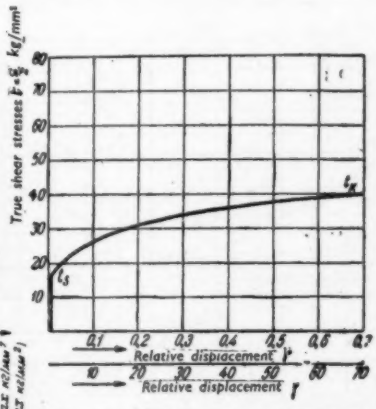


Fig. 7.—Diagram of mechanical state for cast iron (Ch M 1.3) in the annealed condition.

Yield-point, t_S .. .. 17 kg/mm²
Resistance to shear, t_K .. .. 40 "
Resistance to rupture, S_T .. .. 26 "

It is possible to obtain trustworthy results for complex stress states only in the elastic region—limited by the lines t_T and S_T (lower part) in Fig. 5. Calculations of strength of brittle materials, which fail by rupture, give results agreeing well with the experimental. With plastic materials, it is impossible in many cases, from a study of the mechanical properties to indicate even the order in which complex parts made from them will place themselves in respect of strength. This is one of the reasons why calculations of strength of such important constructions as aero-engines are exceedingly difficult.

On the other hand, the analytical methods of calculation which are available—Hooke's law, Prandtl's diagram, etc.—have a fairly high value: (1) For brittle materials, subject to failure immediately after elastic deformation. (2) In many simple cases of deformation (torsion, bend) where, after a certain amount of hardening has occurred, it is possible to evaluate, approximately, the stresses in

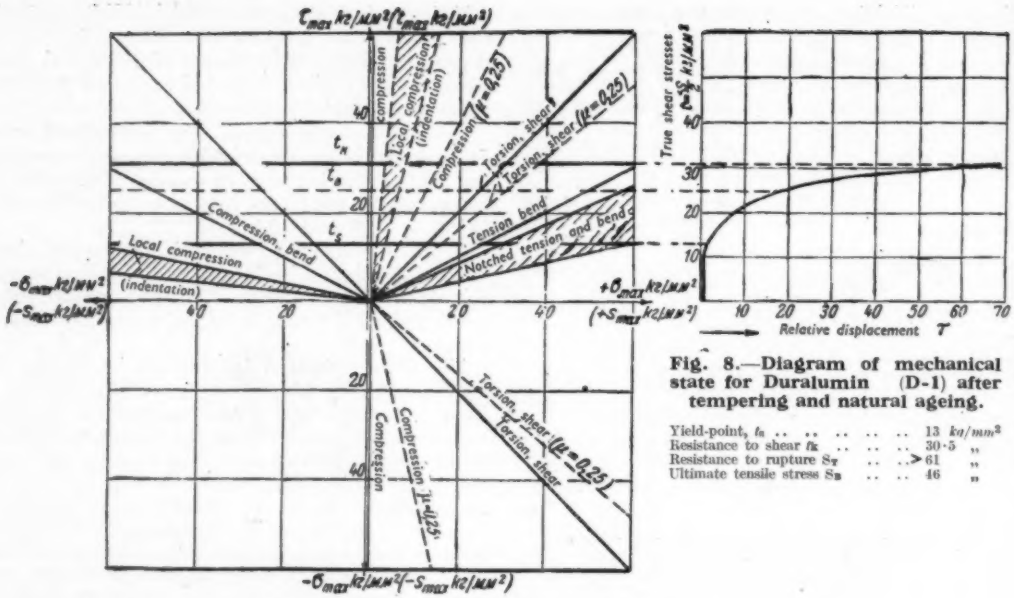


Fig. 8.—Diagram of mechanical state for Duralumin (D-1) after tempering and natural ageing.

Yield-point, t_s	13 kg/mm²
Resistance to shear t_k	30·5 ,,
Resistance to rupture S_T	> 61 ,,
Ultimate tensile stress S_B	46 ,,

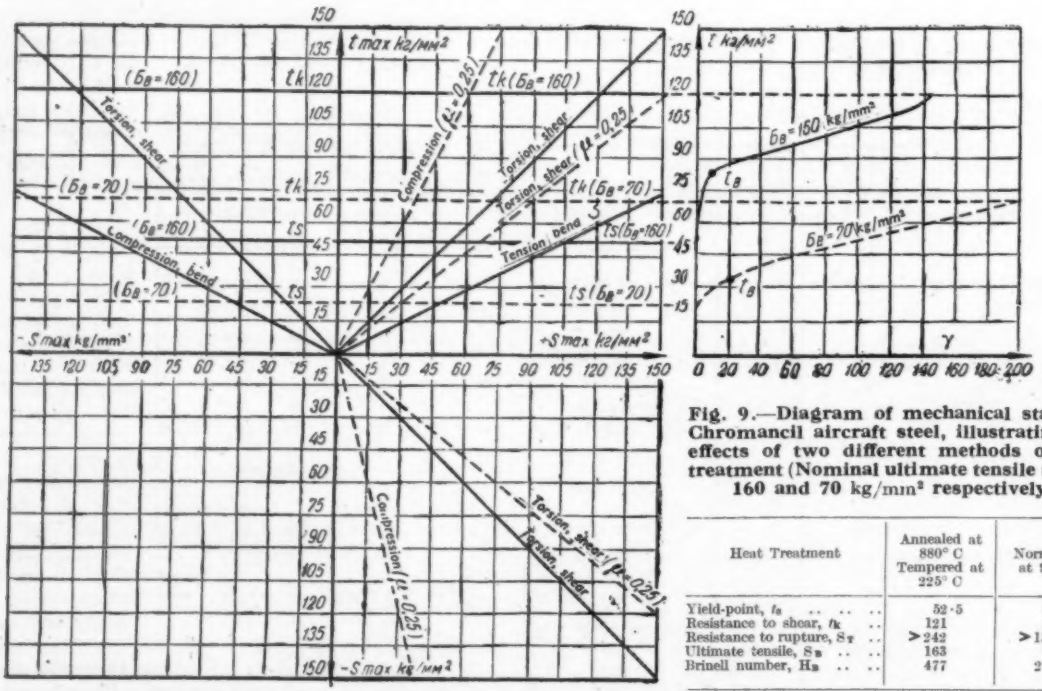


Fig. 9.—Diagram of mechanical state for Chromancil aircraft steel, illustrating the effects of two different methods of heat treatment (Nominal ultimate tensile stress, 160 and 70 kg/mm² respectively).

Heat Treatment	Annealed at 880° C Tempered at 225° C	Normalised at 900° C
Yield-point, t_s	52·5	24
Resistance to shear, t_k	121	68·5
Resistance to rupture, S_T	> 242	> 137
Ultimate tensile, S_B	163	71
Brinell number, H_B	477	215

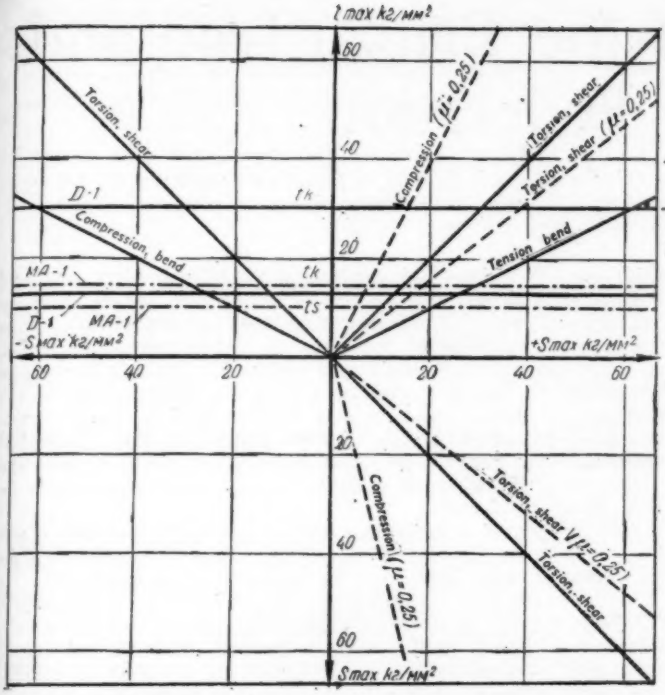
the plastic range. (3) For the accurate fixing of the elastic state of stress which always precedes the plastic.

The further development of analytical methods should lead to means of calculating complex stress distributions after the transition, E → P. As an approximation, the deformation curve may be considered as consisting of two lines of different slope, the angles of which are determined by the moduli of elasticity and plasticity respectively.

Two experimental methods which are giving promise in the study of plastic deformation are particularly referred to by Fridman : Akimov and Pevzner are using the fact that the transformation $\gamma \rightarrow \alpha$ occurs in non-magnetic (austenitic) steels during plastic deformation at 20° with the separation of the α magnetic phase in places of plastic deformation. The quantity of the α phase grows as the deformation increases.

Kishkin has found that during cold plastic deformation of special steels there is a separation of carbides in places of plastic deformation. The quantity is a measure of the deformation.

Both these methods permit a determination of local stresses not only on the surface but, after failure, inside



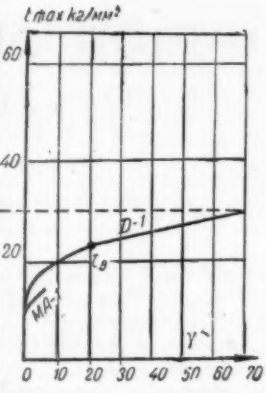


Fig. 10.—Comparison of the mechanical properties of Duralumin (D-1) tempered and aged, and Elektron (MA-1), extruded.

	Duralumin	Elektron
Yield-point, t^s	13	10
Resistance to shear, t_k ..	30·5	15
Resistance to rupture, S_T ..	>61	>30
Ultimate tensile stress, S_B..	46	30

Although the yield-points are close together the resistances to failure (and corresponding properties, plasticity and viscosity) are very different.

at a definite ratio of stresses a displacement of the maximum of the stresses inside the sample does not occur and $\frac{t_{max}}{+S_{mean}} = 0{\cdot}5$. The relationship, $t = F(\sigma_{mean})$, immediately reflects increased non-uniformity (concentration of stress).

Thus, by comparing on the one diagram the curves, $t = f(+S)$ and $t = F(+\sigma_{mean})$ it is possible (1) to evaluate the danger of failure according to the closeness of t to t_k or of t to t_s or of $+S$ to S_T, i.e., to evaluate the reserve of strength in terms of stresses, and (2) to evaluate the danger of failure according to the closeness of $+\sigma_{mean}$ to σ_k or to σ_s or σ_T, i.e., to evaluate the reserve of strength in terms of loading.

It must be admitted that calculations of strength in the plastic range are exceedingly difficult since the properties are not additive and one cannot consider a complex stress state as the sum of several simple states.

the sample. They are hardly developed as yet but it appears that they may be capable of affording accurate information about stress distribution, deformation and the coefficients of concentration in the plastic range.

Evaluations of strength must take into account the actual shape of a section, and the forces which produce plastic deformation or failure in a part of given form. An example of a method of dealing with this matter on the diagram of mechanical state is given schematically in Fig. 11. This figure depicts the distribution of true stresses and conventional stresses (calculated on the assumption that no change of section occurs) in the testing of notched samples in pure tension and tension-bend.

For a smooth (un-notched) sample the curve of mean stresses begins to deviate from the line of stress state during the transition to the plastic range and after the formation of a neck it goes in the opposite direction.

It should be noted that in the elastic range the influence of a notch would not be shown by the line of stress characterising the ratio, $\frac{t_{max}}{S_{max}}$, since on the surface at the notch there exists the stress state, $\frac{t_{max}}{+S_{max}} = 0{\cdot}5$, just the same as in the case of the smooth sample. The curve of mean stresses— and also the curve of forces on the sample—is much steeper in the case of a notched sample, i.e., it shows the concentration effect even in the elastic range.

After the transition which occurs at the yield-point the curve of mean stresses bends to the right (i.e., the sample becomes stronger as the ratio of force to true stress increases) both on account of the reduction in non-uniformity and the effect of volume increase.

In the case of a notched sample in tension-bend the relationship, $t = f(+S)$, is linear not only in the elastic range but also in the plastic since, on account of the additional non-uniformity of stresses from bending,

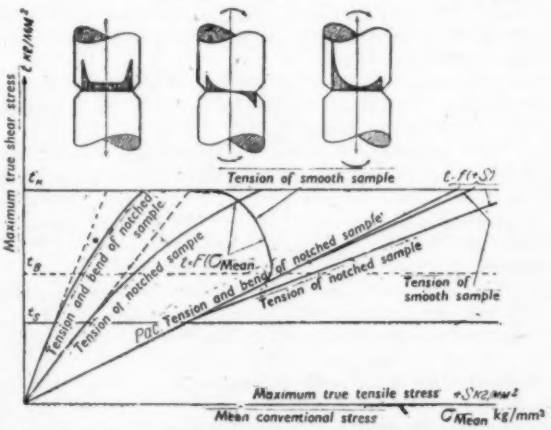


Fig. 11.—A comparison on the diagram of mechanical state of the strength of a material in true stresses [the curves, $t = f(+S)$] and the strength of a part in conventional mean stresses [the curves $t = F(\sigma_{mean})$]. The tangent of the angle of inclination of the curve $t = F(\sigma_{mean})$ to the axis of abscissae is characterised by the effective coefficient of concentration α_k. The smaller α_k is the stronger the part. In the plastic range α_k depends not only upon the form and external loading but also upon the properties of the material (t_s, D).

Constitution of the British Iron and Steel Federation

Essentially the new constitution of this Federation is designed to promote the maximum efficiency in order that it can render efficient service to the community as will be noted from the main fectures of the Articles of Association.

THE British Iron and Steel Federation, which was a reconstitution of the National Federation of Iron and Steel Manufacturers, was formed in April, 1934. The provisions of its Constitution were discussed before their adoption with the Import Duties Advisory Committee, who agreed that the proposed organisation was in conformity with the establishment of an efficient Iron and Steel Industry. In order to meet the conditions expected after the war, certain modifications in the present organisation are necessary. A new Constitution has, therefore, been drawn up by the Executive Committee of the Federation.

The guiding principles are these :—

As a basic supplying industry, to render efficient service to the community.

Self-government within the framework of Government policy.

To develop the industry in all its branches to the greatest possible extent, particularly for export, not only of its own products, but also of other industries using its products ; and to maintain full and regular employment.

To ensure that reasonable and steady rewards are paid to the labour employed and to the savings invested in the Industry.

The Industry, being a highly complex one, must have an organisation which will ensure that while it is united for common purposes, the management is sufficiently decentralised to give full play to enterprise and initiative. The organisation must be the servant of the Industry, and not its master.

To set up an executive body properly representative of all sections of the Industry, elected in such a manner as to ensure that the best men get to the top.

To set up machinery which will provide for constant survey, planning and investigation within the Industry.

The new Draft Constitution is framed on the lines of The Memorandum and Articles of Association of a company, its main features are :—

Whereas at present the members of the Federation consist partly of Associations, regional representatives and individual firms, it is proposed that in future full membership should be confined to the organisations set up by the various sections of the Industry. In other words, membership of the Federation will be confined to Associations, or, as they are termed in the new Constitution, "Conferences."

Except as regards matters of general policy and national or common interest, the Conferences will be free to manage their own affairs. It is essential that such a provision should be made because, as has been pointed out, the Industry is so diverse that efficiency and initiative would be impaired by any form of centralised control, except upon matters of general policy and common interest.

The Conferences in the particular form envisaged do not exist at present. Time will, consequently, be required for their formation, or for the adaptation of existing Associations. While complete freedom will be given to the various Conferences to organise their particular section of the Industry, in such a manner as may seem to them to be the most appropriate, certain definite clauses in their individual Constitutions must be common to all, so that the Industry as a whole may be enabled to attain its objectives.

The Federation will be governed by a Council and an Executive Committee. Each Conference will be represented on the Council in proportion to its relative importance, and in addition due weight will be given to the complexity of each section of the trade within the Conference, with the object of ensuring that the Council as a whole is a truly representative body. The Executive Committee will be chosen from the members of the Council, with the proviso that each Conference must be represented.

The status of the members, both of the Council and of the Executive Committee, is defined so as to ensure that these bodies will consist solely of persons directly responsible for management in their own companies. Provision is also made for the appointment of additional individuals of outstanding personality to the Council and the Executive Committee.

The Executive Committee will thus not only consist of the leaders of the Industry, with power to act, but these leaders will have been elected democratically by the various sections of the Industry.

There will be a chief executive officer of the Federation, chosen from outside the Industry, who will act as Chairman of the Executive Committee. Apart from his executive duties in putting into practice the general policy of the Industry as the Executive Committee may from time to time determine, he will act as impartial adviser to the Conferences and to individual firms as may be required.

Provision is made for appeal to an independent tribunal by any Conference or any firm.

Provision is made whereby any Association within the United Kingdom which is directly or indirectly concerned with the Industry, can become an affiliated member of the Federation. Similarly, provision is made for affiliation of the iron and steel manufacturers in the Dominions.

Various standing Committees are set up under the ægis of the Executive Committee, amongst which are the Economic Efficiency Committee and the Price Policy Committee. The former will be responsible for ensuring that the technical efficiency of the Industry is maintained ; its functions will be not only to advise on proposed schemes of expansion or reconstruction, but to make a survey of each of the main sections of

the Industry, and actively to stimulate modernisation when and if necessary. In connection with the functions of the Price Policy Committee, it should be stated that the Industry would welcome in the post-war era, the setting up by the Government of a tribunal such as the Import Duties Advisory Committee, to examine the costs of the Industry in relation to selling prices. The general policy of the Industry as regards selling prices is that they should be based upon the costs of economically efficient plants, and that it should be accepted as a fundamental principle that such plants are enabled not only to obtain a reasonable return on the capital invested but also to set aside a sufficient amount towards research and development.

The new Constitution is designed to promote maximum efficiency; give full play to enterprise; and at the same time avoid the stifling of initiative by dictation or bureaucratic control.

American and Canadian Patents

By S. T. Madeley

Problems frequently arise regarding patents and patent rights in normal times, but war increases the complexities. Here the author endeavours to clarify the position with American and Canadian Patents.

PERHAPS it is as well first to take Canadian Patents because of the rapidly growing development of Canadian metalliferous resources and because Canada has a Patents Emergency Act on the same lines as our own. Although legislation on similar lines in the United States of America has been before Congress for some time no decisive action has yet been taken in this direction.

The Canadian Emergency Act enables the Commissioner of Patents at Ottawa to grant extensions of time for carrying out patent procedure, e.g., late filing of patent applications under the International Convention where delay has been caused by the war; similarly for filing responses and so on.

Provisional specifications, cognates and patents of addition are unknown in Canada, where complete specifications must be filed in first instance. There is no time limit for acceptance. The specification and claim are drawn in the American style, that is to say, with a series of claims which are generally independent. Normally a response to an official action is due within six months. The search into novelty is usually confined to Canadian Specifications. The examiner may, however, require disclosure of the prior act cited by the examiners of other countries in which corresponding patent applications have been filed. Patents are granted for seventeen years from the date of issue and there are no renewal fees. Appeal from the Canadian Courts is to the Privy Council in Patent cases.

In the United States, provisionals, cognates, and patents of addition are also unknown. Acceptance is not subject to time limit. There is but little difference between an American Specification and our complete beyond their custom of drafting independent claims; although now American examiners will accept subsidiary claims tacked on to a main claim. Their novelty search is theoretically world-wide and it covers British, German and French specifications, besides technical literature. Official actions have to be answered within six months of mailing date, which comes pretty hard on British applicants, for example, owing to postal delays. This six months is inextensible, since the U.S.A. has no Emergency Act, as above mentioned. It has been suggested that under certain circumstances the Commissioner might reinstate a case, where the response is late, where, for example, the delay has occurred through the British patent agent having had his premises destroyed by enemy action. Should it happen that owing to the war an inventor cannot himself formally complete his patent application documents as required by American Law, for examination purposes only the American Patent Office will admit informal documents. However, documents which have been properly sworn and validated will be required before the Patent issues.

In cases where an American application emanating from abroad is not filed within the twelve months allowed by the International Convention, the American Patent must be the first to issue. This frequently makes it difficult to handle the American case properly on account of the pressure of time, and means extra cost to the applicant, as he must pay extension fees to the British Patent Office to delay Sealing of the British patent until the American issues.

An American Patent can, however, be re-examined after issue and, under certain circumstances, on occasion be re-issued with wider claims. Canada also does this.

Conceivably this may provide a method of improving unsatisfactory claims obtained owing to circumstances arising out of the war.

An American patent lasts for seventeen years from the date of issue and is not subject to renewal fees.

Patent cases may be heard in first instance in the Court of the relevant State of the Union which in the ordinary way will not have had, comparatively, much experience in patent litigation. The final appeal is to the Supreme Court of the Union, which is, of course, well versed in such matters.

Section six of our Emergency Act has been suspended as regards applications coming from the United States and claiming priority under the International Convention until America grants us similar privileges.

Permission has to be obtained from the U.S. Censor before technical data can be despatched from the United States to other countries.

It is not allowable for American patents attorneys to act in patent matters relating to enemy-countries or those of enemy subjects.

British subjects resident in the United Kingdom who desire to file patent applications in the United States must first obtain permission of the Patent Office in

London. Furthermore, all outgoing correspondence in connection with such matters must pass the Patent Office Censor.

Where an invention, for which patent application has been made in the United States is of interest to the British Minister of Supply, of Aircraft, Production or to the Admiralty, the applicant must agree that he and his successors in title will hold themselves free to grant such licences in connection with the invention and upon agreed terms, as may be required by the Governments of the United Kingdom or the United States, concerning manufacture for war purposes of that invention in the United States.

Should the American Commissioner of Patents make a U.S. patent application, for example, for a light alloy "secret," the applicant must tender that invention for the use of the American Government, and he may not lodge a claim against that Government without previously having obtained written permission of the British Government.

In the case of a United States patent which has already been issued and under which a British subject has rights, the British Government may order him to grant a licence authorising the use of that invention in the U.S.A. for war purposes. Our Government may also forbid him to transfer that right unless he has their written permission so to do, and even not allow him to enter into an agreement to give information for facilitating manufacture in the United States.

Exceptions are made to this rule.

The American Government may take over and operate patent rights owned by foreigners who are unable to exercise those rights owing to the war. Where British subjects own American patent rights, the American Government treats those in the same way as it does similar rights of American subjects. But where U.S. patent rights of enemies or enemy-subjects are concerned and where such may be useful for war purposes, the Alien Property Custodian will seize them and operate them by licence.

An agreement made in August, 1942, between the United Kingdom and the United States concerned interchange of patent rights and information deals with matters indicated in the title thereof under the Lend-Lease procedure in a far-reaching manner.

In our Patent Act we have a section (number 27) which enables a manufacturer to apply for a compulsory licence under a patent if the patentee has failed to supply the public requirements in respect of sale of the patented article. It is thought by instructed opinion that this section has had a sufficiently deterrent effect to prevent British patents in general being used adversely to the public interest. No such provisions are to be found in the patent legislation of the United States.

It has been said that the patents in America have been used oppressively by patent pools and cartels. Perhaps also the way in which patent litigation can be fought may have had something to do with the accusation.

Be that as it may, complaints of this nature are being investigated by the Temporary National Committee of Congress. Furthermore, the Sherman Anti-Trust Law has been invoked and the Courts deal drastically with offenders. The penalties may extend to stripping them of all Patent rights.

War Industries in Northern Ireland

THERE is a tendency to overlook the contributions of Northern Ireland to the war effort, especially in the industrial field. This has been due largely to the need for security, but information has been released which reveals the magnitude of the effort made by Northern Ireland in the critical years of the war against Germany. In the grim period of 1940 and 1941 she transformed herself into an arsenal and the transformation extended to almost every field of industry. Every other consideration was brushed aside and the result has been a record of production in which the people can feel justifiably proud.

In the five years, 1940-1944, for the Navy, the Queen's Island alone constructed 140 warships and 123 merchant vessels. Naval construction included six aircraft carriers, three cruisers, two large depot ships and a host of corvettes, minesweepers, frigates and other craft. The merchant shipbuilding represented approximately 600,000 tons, or 10% of the total merchant building of the United Kingdom. But this was not all. The smaller yards were also busy and turned our large numbers of landing craft, launches, whalers and other light vessels, whilst engineering shops contributed ships' fittings of every kind and, amongst other things, components for the Mulberry ports.

For the Army, Northern Ireland has produced nearly 500 tanks and over 500 guns, together with 14,000 gun barrels and other gun parts, to say nothing of 42,000 carbine machine guns. In the field of ammunition she has produced approximately 75,000,000 shells and 180,000,000 incendiary bullets. In addition she has made 50,000 bayonets—enough for an entire Army Corps.

For the Air Force Northern Ireland has constructed 1,500 heavy bombers—sufficient to put 100 squadrons in the air—and carried out repairs to approximately 3,000 heavy, medium and light aircraft. Nor is this all for she has also made a substantial contribution in the field of aircraft components, to say nothing of over 2,000,000 parachutes and miscellaneous supplies.

Sheffield Society of Technical Inspection

THE above Society have organised an exhibition to be held in the Cutler's Hall, Sheffield, from August 20 to 25, at which a wide range of inspection equipment will be exhibited. It will be of interest to many readers that included amongst the exhibits are a Spekker Photo-electric Absorptiometer and a Spekker Steeloscope.

British Non-Ferrous Metals Research Association

THE Information Department and Library, and the Corrosion Section of the Research Department are returning from Berkhamsted to Euston Street. As from August 23rd, all communications to the Association should therefore be directed to Euston Street, London, N.W.1., and not to Berkhamsted.

The Water Quenching of Steel Castings

Developments in the water quenching of steel castings, problems in the quenching of miscellaneous sized castings, design and mass in water quenching, the water quenching of small and of large castings, and facilities for water quenching steel castings, were aspects of the subject discussed at a recent meeting of the Steel Founders' Society of America. The main points considered are briefly reviewed.

THE water quenching of steel castings to increase strength and hardness has been in practice for many years, but its use introduces many problems. In many instances the castings are fully annealed or normalised previously and then quenched from slightly above the upper critical range; in others satisfactory results are obtained by a single treatment, quenching from a temperature near to the ordinary normalising temperature, followed by tempering. Many aspects of the subject were presented at a recent meeting of the Steel Founders' Society of America, some of which are discussed here.

Dealing with developments in the water quenching of steel castings, C. W. Briggs[1] reviewed the history of liquid quenching of commercial steel castings for the last 35 years, and showed that up to 1930, leading specifications for steel castings did not favour water quenching. It was not until 1935 that a tentative specification was adopted by the American Society for Testing Materials permitting liquid quenching and tempering of steel castings. Other specifications were then issued, permitting such treatment by agreement between the user and the producer, and by 1939 practically all of the A.S.T.M. steel casting specifications carried clauses giving requirements necessary for liquid quenching.

Up to 1940 only a low tonnage of steel castings was produced with a quench and temper heat treatment. In that year the total production of castings so treated did not exceed 5,000 tons, less than 5% of the electric alloy steel production or less than one-half of 1% of the entire casting production. By 1943, however, a considerable change had taken place and at least 8% of the entire casting production was quenched and tempered This had resulted from a wider knowledge of the properties obtained by water quenching of both carbon and alloy steel castings, resulting in yield strengths and tensile strengths exceeding those obtained by annealing, normalising, or oil-quenching and tempering. The wartime demand for high-strength casting also helped development, but there are indications that such treatments will be adopted in the future for the production of commercial castings and that a much larger proportion of the alloy steel casting production will be produced for use as water-quenched and tempered castings.

Quenching Miscellaneous Steel Castings

The problems of water quenching of miscellaneous steel castings, dealt with by W. B. Libert[2], are care in loading so as to get uniformity of loads, positioning of the castings so as to eliminate steam or water pocketing, spacing of castings so as to get maximum effect from the quenching media, adequate blocking to prevent warpage and blocking-off of sections critically from the standpoint of quench cracking, uniformity of heating and holding temperatures, speed of getting quench load from furnace into the quenching media, and proper quenching practice to get maximum properties from the steel used.

Due to the design of most medium or medium-large sized castings, up to 2,000 lb., which are quenched in racks, it is impossible to get ideal uniformity of loading so that heating control must be flexible. This is usually carried out by suitable burner control and the use of flues. To prevent warpage of intricate designed or large castings, considerable care is necessary in blocking up the castings in the rack or in the car, when a car type furnace is used. The particular design being quenched has to be studied in such a manner as not to pocket any steam during the quenching and not to pocket any water upon lifting it out of the quenching media. In addition to agitation, due to circulation, it is good practice to keep the quench load moving back and forward in the quenching tank to break up the steam film on the casting surface.

Timed and intermittent quenching are generally used for most normal quenching operations, where castings are of both heavy and light sections and where castings have abrupt changes of sections. In order to utilise such procedure to the full, the types of loads must be controlled, and, if quenching is to be done on racks, it is necessary to have similar castings on each rack. Another very important consideration in the quenching of miscellaneous steel castings is that the quench loads must be of such a size and character that the quenching media will contact all the castings involved in the load.

Quenching Small Castings

Procedures in the water quenching of small steel castings were described by J. W. Juppenlatz,[3] who states that the fundamental requirements of such heat treatment are sound metallurgical information on the type of the steels involved, such as its content of hardenability elements, grain size, methods of melting and oxidation; uniform arrangement of castings to assure adequate circulation of hot gases upon heating for quenching; rapid removal of the castings from the furnace, and quenching at known cooling rates so that the austenite transforms into martensite without crack formation; proper tempering for the required period of time to ensure a ductile structure; and appropriate

1 *The Foundry*, 1944, Vol. 72, No. 5, pp. 58, 59, 132.
2 *The Foundry*, 1944, Vol. No. 72, No. 6, pp. 130, 131, 256, 258.
3 *The Foundry*, 1944, Vol. 72, No. 7, pp. 84–87, 174.

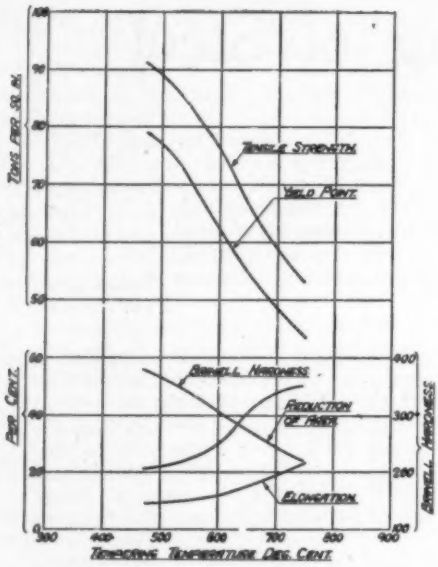


Fig. 1.—Average physical properties of a water quenched nickel-chromium-molybdenum cast steel.

testing to determine that the required physical properties have been secured in the castings.

To secure these requirements proper loading of well cleaned castings, free of sand or excessive scale, in a furnace of suitable design either of the batch or continuous type, is the first requirement. Castings should follow the ambient furnace temperature with a small lag, the extent of which can be first ascertained by thermocouples within the load and later by comparative observation. Predetermination of hardenability by Jominy tests are recommended, and controlled time quenching should be carried out so as to prevent underquenching or overquenching, and in order to obtain satisfactory hardening in the heavier sections without cracking of the lighter sections. The accurate control of tempering furnaces within a narrow range is also necessary, as otherwise large differences in strength properties can be obtained, Fig. 1.

The advantages of water quenching of small steel castings are increased physical properties, and the effectiveness of the heat-treatment should be rigidly checked by physical methods such as tensile, Brinell and impact tests.

Influence of Size and Shape of Castings

The influence of the size and shape of steel castings on practice followed in their water quenching were discussed in the fourth paper of the series by W. J. Phillips[4]. The requisite factors for successful treatment are considered to be steel of sufficient hardenability for the section size involved, a quenching bath of such capacity and rate of flow that the surface of the piece being quenched approaches the temperature of the quenching medium, and removal of the quenched part before its temperature falls below 120° C. to avoid the risk of quench cracking, which is greatly increased if the temperature of the part is allowed to drop much below 120° C., before being tempered. In establishing those factors, mass and design play an important part.

4 *The Foundry*, 1944, Vol. 72, No. 8, pp. 89, 201, 202, 204.

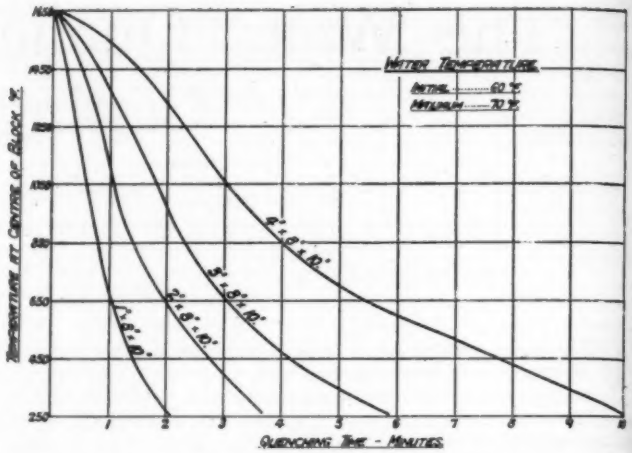


Fig. 2.—Cooling curves for various sized blocks.

Mass, in the sense of thickness, determines the choice of composition of the steel, and the composition must confer suitable hardenability upon the steel to ensure the quenching out of the heaviest section. Mass determines the quench tank capacity and amount of circulation of water. Mass also limits the time that the piece may be allowed to remain in the quenching medium and the production handling throughout the quench. Design, in the sense of varying masses, limits the practicability of water quenching in accordance with the means employed to join sections of varying thicknesses. In Fig. 2 are given curves showing the cooling rates for various sized cast-steel blocks.

In tempering, it has been fairly well established that for 1- and 2- in. sections 6 hours at the tempering temperature is not unduly long for the removal or relief of quenching stresses and the complete tempering of martensite. Heavier sections may profitably be tempered for a period of time varying from 8 to 12 hours. The result of such treatment after full quenching is a steel with maximum resistance to high rates of stress application.

Quenching Large Castings

Liquid quenching of large steel castings has not been common practice until the last few years. This has probably been due to the opinion that such treatment of castings was dangerous practice and did not produce satisfactory results and to the viewpoint that parts with varying thicknesses must be oil quenched. Experience gained, however, has proved that satisfactory results can be obtained by properly controlled water quenching of large steel castings, provided the general procedures used for steel castings are adopted. The sizes of the castings make individual handling desirable in many cases and equipment used for such a purpose was dealt with by R. A. Gezelius.[5]

For the treatments of castings up to 3 tons in weight, a semi-continuous, gas-fired furnace, 73 ft. long and 8 × 5 ft. in cross section has been used successfully for heating prior to quenching and for tempering. Such a furnace is divided into five zones. The first zone, which contains two castings, has no burners and the castings are heated only by the waste heat from the hotter zones ahead of them. The second and third zones, which also contain two castings, are heating zones in which the

5 *The Foundry*, 1944, Vol. 72, No. 9, pp. 74–77, 176, 178.

castings are slowly brought up to the quenching temperature. The fourth zone also contains two castings and is maintained at the quenching temperature and provides a portion of the "soaking period" required. The last zone contains only one casting and is used to adjust any slight variations in temperature which may occur in the fourth zone. Castings are carried through the furnace on hangers suspended from mono-rail conveyers.

For castings weighing approximately 10 tons and 40 tons, a car-type, gas-fired, pyrometrically controlled furnace, 34 × 15 × 10 ft., was found to be satisfactory for heating for quenching and for tempering. With proper equipment approximately 45 seconds was required to remove the casting from the furnace and immerse it in water contained in a 66,000 gallon tank recirculated at the rate of 6,000 gallons per minute.

In all of these quenching operations, the length of time the casting was immersed in water was determined experimentally so as to allow sufficient time to decrease the temperature of the heaviest section to less than 260° C. The time was adjusted so that the temperature of the heaviest section was as low as possible without bringing the temperature of the thinnest section below 120° C., thus reducing cracking to a minimum. Once the proper quenching time has been determined for a particular casting, each casting of that design can be treated in the same manner.

Quenching Facilities

In the sixth paper of the series, three factors in the water quenching of steel castings, type of steel, furnace equipment and quench facilities are discussed by R. H. Schwarz.[6] Every type of steel has a critical cooling rate necessary to harden it fully, and its composition must also be studied from the standpoint of its heaviest section. A change of carbon or alloy content generally moves the nose of the S-curve back to the right for each steel, making the necessary critical cooling rate less, or making it possible to quench out heavier sections at the same critical cooling rate. The surface per unit of volume, size and shape of the piece, temperature of the water, temperature of casting when quenched, diffusivity of the casting, surface condition of the steel, liberation of gases in the bath, methods of introduction into the bath and circulation and agitation of the water must each be studied carefully and understood to attain any degree of consistency or accuracy of quenching for each type of steel.

The types of quenching generally used and accepted in steel foundries can be divided into three groups—batch, semi-continuous and continuous. Batch quenching covers a large variety of types from one single furnace load to several group loads in one furnace. The work is charged in a batch furnace and either removed as a total and quenched or removed in smaller units and quenched. Large, individual, bulky castings work well when quenched from a batch furnace.

Semi-continuous quenching is carried out in a longer furnace with some pusher-type arrangement where, when castings are loaded and pushed, the equivalent area of furnace is pushed out by the same pusher mechanism; or, where only one door opens at a time, the quench load is then pulled and quenched leaving a vacant area to be filled by the pusher when the outgoing door closes and the ingoing door opens. This type of furnace is very good for the general run of heat-treating steel castings. The completely continuous system of quenching is only slightly used by steel foundries, except for some specialised work and then for relatively small castings where large quantities are handled, when it is an ideal method from the standpoint of economy, metallurgical control and consistent results.

[6] *The Foundry*, 1944, Vol. 72, No. 10, p. 8p2–84, 230, 232, 234, 236.

Reviews of Current Literature

The British Wire Process of Metal Spraying

This book gives full working instructions in the use of the Mark 16 metal spraying pistol and can be regarded as a practical handbook on its installation and operation and also on the use of metal sprayed coatings. Useful advice to operators is given on the use of the metal spraying pistol and, in order to assist in the successful working of this precision tool, troubles likely to be encountered are tabulated with their causes and remedies. Another table of equal importance gives gas pressures for the different gases which may be used, together with the wire diameter of the metal to be sprayed and the speed at which the wire should be fed Considerable experience is obviously necessary to facilitate trouble-free operation of this valuable tool, but the instructions given in this handbook should prove invaluable to this end.

The application of metal spraying can be conveniently divided under two main headings: the formation of protective coatings, and the building up or reclamation of worn parts. A special chapter is allocated to this latter important aspect of metal spraying. In addition useful notes are given on the use of sprayed coatings, and for convenience the various metals, which may be sprayed, are considered in the order of their melting points.

Apart from the useful information given in this handbook for both operators and users of the process, it is admirably presented and illustrated.

Published by Metallisation Ltd. Barclays Bank, Chambers, Dudley. Price 5s. 6d.

Shrinkage and Gas Effects in the Casting of Non-Ferrous Metals and Alloys

This is a report prepared to provide a survey of the results of various researches on shrinkage and gas effects, which are the most obstinate sources of difficulty in castings. It is based upon the results of the British Non-Ferrous Metals Research Association and other researches, and references are given to reports, etc., containing detailed information. Methods of obviating the ill effects of shrinkage and gas on castings are given. The fundamental mechanisms of the processes concerned are explained in terms which do not assume specialised knowledge on the part of the reader. Practical recommendations are given and a bibliography of 58 references.

By W. A. Baker, B.Sc., Report R.R.A. 661, published by the British Non-Ferrous Metals Research Association, Euston St., London, N.W.1, price 7s. 6d.

Damping Capacity

A CRITICAL survey of the present state of knowledge on the subject of damping capacity is given in this report. In addition to a consideration of the fundamentals of damping capacity, the report discusses its metallurgical and mechanical significance and the validity of present methods of determining it. Suggestions are made of directions in which future experimental work might prove fruitful. The survey was prepared to guide the B.N.F.M.R.A. Main Research Committee in considering the desirability of initiating research on the subject. No attempt has been made in it to produce a compilation of numerical data. There is a bibliography of 58 references supplementing existing bibliographies to which reference is made.

By Professor F. C. Thompson, D.Met., M.Sc., Report R.R.A. 657, published by the British Non-Ferrous Metals Research Association, Euston Street, London, N.W.1, price 3s. 6d.

Diamond Tool Patents for Machining Metals and Non-Metallic Substances

THE extraordinary increase in the use of diamond tools for the machining of the hardest known substances has naturally been accompanied by the issue of a very considerable number of patents on the subject. Searching patent literature, however, is a long, arduous and expert job, and one that even those interested in the use of diamond tools might shrink from undertaking, so that the present work will be welcomed by those wish to go further into this subject.

It consists of a list of about 100 patents, issued in England, America, and Germany, on the machining of metals and non-metallic substances by means of diamond tools. For each patent, the number, title, and date of application is given, together with an abstract of its principal contents, usually accompanied by a sketch illustrating the invention. Furthermore, a table has been compiled, sub-dividing the subject matter into definite groups, such as turning, boring, and milling; it is also sub-divided into classes such as tool-shape, tool-setting, tool holder and adjustment, auxiliary equipment, as well as according to the materials machined and the service data contained.

At a later date it is intended to bring out similar compilations relating to other fields in connection with diamond tools.

By P. Grodzinski, A.M.I.Mech.E., and W. Jacobsohn, A.M.I.Mech.E. (London: Diamond Trading Co., Ltd., 1945). 16 pp. $9\frac{3}{4} \times 7\frac{1}{4}$ in. Price, by post, 1s. 6d.

Science in Britain

UNDER the auspices of the British Council's Publications Department, engineering booklets forming part of a "Science in Britain" series are being published. These mainly comprise short illustrated biographies of eminent British engineers and those dealing with Sir Charles Parsons, James Watt, and S. Z. de Ferranti, have been published. A further two booklets in this series have now become available dealing with Sir Henry Royce and Colonel R. E. Crompton. The former is by G. Geoffrey Smith, M.B.E., who outlines Royce's contributions to engineering progress. The remarkable engineering products of Sir Henry are known throughout the world, but although his work brought him lasting fame, he was seldom much in the public eye, yet by adding technical superiority to the incomparable bravery and skill of our pilots in the Battle of Britain he made a major contribution to the cause of liberty.

The second booklet is by J. H. Johnson and W. L. Randall who knew Col. Crompton well and had first hand experience of the unfailing generosity with help and advice which made this eminent engineer a source of inspiration. Col. Crompton exerted a considerable influence upon the early development of mechanical land transport, and found further scope for his ingenuity and skill in connection with the evolution of the internal combustion engine, but his major contributions to progress primarily concern electric power plant and associated appliances.

The booklets are admirably written and are both interesting and informative; they help to make us familiar with men who have contributed so much to British engineering. Published for the British Council by Longmans Green and Company, price 1s. each.

Chronology of the Tinplate Works of Great Britain

THIS work is the successor to a work entitled "Monograph on the Tinplate Works of Great Britain," issued in 1932, which included the data collected by the author's father from 1863 to 1906 and by himself from 1904 to 1932. The current volume in addition to being rather fuller than the Monograph, also brings the history of the British Tinplate industry up to date.

There is a tremendous amount of information in this work and according to the author's description of the method by which the details were vetted, it may be taken as extremely reliable. The method of treatment is alphabetical according to the names of the various companies. In addition to tracing the history of each company, such details as nature and capacity of plant, nature of products and brand marks, capitalisation, directors, etc., are also given. Useful statistics relating to the tinplate industry are given, and the work concludes with some contributed articles on the International Tinplate Cartel.

By E. H. Brooke. (Cardiff: Wm. Lewis, Ltd., 1944). 177 pp. $8\frac{1}{2} \times 5\frac{1}{2}$ in. Price 8s., post free.

Research

WITH the object of encouraging individuals to study and improve their education beyond the examination stage, an Advisory Bureau of Research has been formed. In addition to recommending problems for research, suggesting methods of treatment, etc., the Bureau is arranging the publication of a series of booklets, the first of which, entitled research, is now available.

Systematic exploration of a subject avoids confusion, reduces the possibility of premature conclusions, indicates the often unexpected influence of one factor upon another, and results in the final application of a discovery or development for the greatest benefit of mankind. It is this research which is the basis of industrial progress and this booklet gives useful information on the origins of research and its uses.

Published by Advisory Bureau for Research, 70, Victoria Street, London, S.W.1. Price 1s. 5d. post free.

A New Departure in the Control of Furnace Dampers

The fine adjustment of a heat-treatment furnace damper plays an important part in the maintenance of controlled atmosphere conditions within the furnace chamber, but the damper control unit described is a new development.

ALTHOUGH the extensive application of automatic temperature control to all phases of industrial heating equipment has made it more than ever necessary to ensure the maintenance of constant draught conditions in industrial furnaces, the regulation of stack dampers by automatic means has so far only been achieved by what at best may be termed "compromise methods," whereby the draught conditions are controlled within rather wide limits by means of a mechanically operated butterfly valve actuated in terms of temperature by the automatic temperature control equipment.

It is nevertheless a well-known fact that the fine adjustment of a furnace damper plays an important part in the maintenance of correct atmosphere conditions within the furnace chamber, and such adjustment should be made not in terms of furnace temperature, but in terms of pressure, and in fact the skilled operator to-day will make his damper adjustment on the basis of the behaviour of the flame of a lighted match held to the spy hole of the furnace door.

If maximum protection is to be given to the work under treatment, the operator will close his damper until there is a very slight positive plenum inside the furnace working chamber, thereby avoiding the influx of cold air which would damage the work and incidentally lower the efficiency of the furnace.

In the modern natural draught underfired gas furnace, it is important if the best results are to be secured, that the damper should be closed sufficiently to ensure a slight plenum in the furnace chamber, while it must not be closed to such an extent that there is an insufficient pull at the secondary air inlets generally provided in the recuperative system under the hearth.

When it is realised that in many furnaces the difference in level between the secondary air inlets, which must be under suction, and the bottom of the door, which should be under a slight pressure, is only a matter of 1 ft. or less, and when it is further realised that the "hot leg" effect on which draught depends, is only approximately 0·01 in. w.g. per ft. of height, the complexity of the problem of regulating a damper in terms of pressure will be readily appreciated.

Effectively, as the total pressure potential from the negative secondary air inlet to the positive point at the bottom of the door is only about 0·01 in. w.g., it is desirable that any pressure controller which may be used to regulate the damper should be sensitive to pressure variations of the order of 0·001 in. w.g. if correct operating conditions are to be maintained at all times.

The damper control unit recently developed by The Incandescent Heat Company, and illustrated on Fig. 1, is, in fact, sensitive to pressure variations of less than 0·001 in. w.g., and the operation of this unit can be briefly described as follows :—

An ultra sensitive manometer, sensitive to the nearest 0·001 in. w.g., is connected by a pressure leg to the furnace chamber, and this unit operates a fractional h.p. motor connected to the furnace damper.

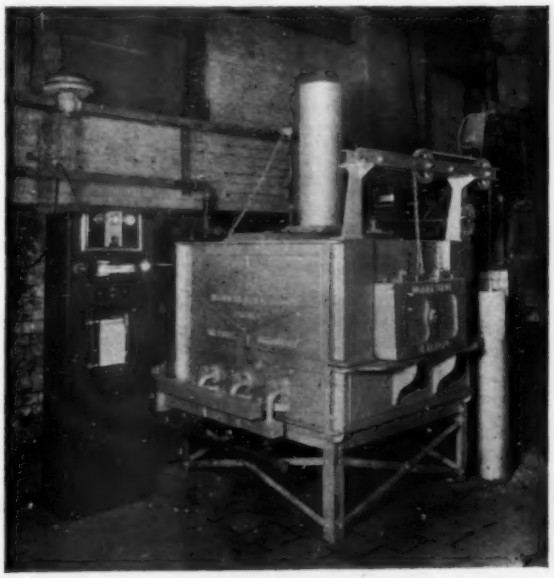


Fig. 1.—The temperature control unit applied to a small general heat-treatment furnace.

In operation the damper responds positively and instantly to any pressure variation in the furnace chamber from whatever cause, and even a shop draught, or change of barometric conditions, will immediately be taken care of.

In the case of furnaces fitted with automatic temperature control, a reduction of gas or air supply will immediately lead to a corresponding alteration to the damper settings, and in a word, absolutely constant pressure conditions within the chamber will always be assured.

A further feature, is that the gear is so fitted to the furnace, that the waste gas damper will close as soon as the furnace door is opened for charging or discharging operations and will automatically open again by precisely the right amount as soon as the door is closed.

It is important to note that this constant pressure or plenum will be maintained in the furnace chamber whatever the operating temperature, as while if great care is exercised it is possible with the conventional mechanically operated butterfly to obtain reasonably constant draught conditions both on full gas and on turn-down at a given temperature in a furnace fitted with conventional automatic temperature and damper control, this result cannot be achieved even in theory

with a butterfly damper operated through the temperature control equipment at more than one temperature unless alterations are made to the linings for each temperature condition in the furnace and it would be theoretically necessary, though practically impossible, to make such alterations constantly as a furnace is recovering temperature after insertion of a cold load.

With the Incandescent system of damper control identically the same plenum is maintained at low or high temperature and at full-on or turn-down gas ratings.

The practical value of this device can readily be measured by a study of the curve shown on Fig. 2 herewith, which was taken from a CO_2 recorder fitted to a furnace provided with the Incandescent Damper control system.

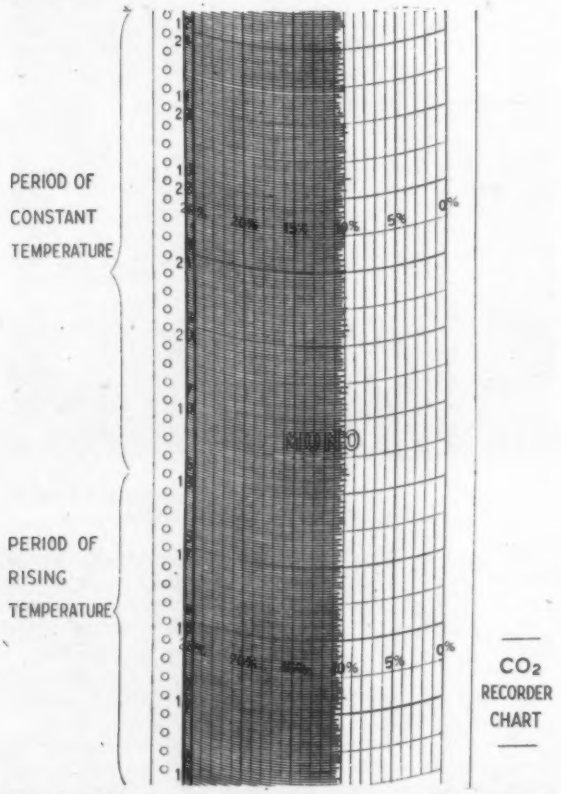


Fig. 2.—Section of a chart taken from a CO_2 Recorder fitted to a furnace provided with the Damper Control System.

During the run shown by this curve, the furnace temperature was increased from 600° to 850° in the first period, and then maintained constant at 859° by means of a conventional "on/off" type automatic temperature control unit.

It will be noted that not only during the period of temperature variation, but above all, during the period at constant temperature when the gas supply was going from full-on to turn-down at approximately 3 minute intervals, the CO_2 content of the waste gases never varied by more than 0·25% between limits of 10% and 10·50%, which within practical limitations can be said to be a straight line CO_2 curve.

While the importance of maintaining constant CO_2 conditions on a furnace fitted with automatic temperature control equipment, is too obvious to require stressing, from the view point of overall efficiency it should be noted that the makers advance no claim of economy in relation to this apparatus, preferring to stress the still more important angle that the maintenance of constant waste gas and consequently furnace chamber atmosphere conditions, is of vital importance in the heat-treatment of metals for the avoidance either of excessive oxidation or surface decarburisation.

To obtain the virtually perfect combustion conditions, illustrated by the graph, the natural draught furnace used for the test was fitted with automatic control of the air supply, involving some very minor additions to the maker's normal design of natural draught furnace and this subsidiary air control can be fitted in the vast majority of cases without difficulty.

Briefly the primary and secondary air supply to each natural draught burner provided on the furnace is mechanically operated from the automatic temperature equipment in the following way :—

When the furnace is "on gas" any required amount of air can be admitted through the primary and secondary air slides respectively, but the arrangement is such that when the furnace comes on to "turn-down" the primary air slides are fully closed, eliminating any possibility of lighting back troubles, while the secondary air slides are closed by the requisite proportion to ensure the maintenance of the same combustion conditions "on turn-down" as had previously been set on gas.

The final point which it is interesting to note, is, that although the manometer is so highly sensitive, it is remarkably free from the effects of external vibration, and the component parts have proved themselves under arduous industrial conditions over many years.

Personal

Dr. Douglas Rennie Hudson, Lecturer in Metallurgy at the Heriot-Watt College and University, Edinburgh, has been appointed Lecturer in Metallurgy at Leeds University. With the exception of three years' service with the army, part of which was spent in Woolwich Arsenal, at the Research Department, Dr. Hudson has been at Edibnurgh since 1932, having previously served two years at the National Physical Laboratory. He has published a large number of papers on the physical properties of amalgams, and on use of metals in antiquity. Many of his memoirs on the latter subject have appeared in this Journal, and will be familiar to readers.

David Brown and Sons (Huddersfield) Limited, have notified us that they have now opened an area office at 109, Pilgrim Street, Newcastle-upon-Tyne. The telephone number is "Newcastle-upon-Tyne 20902" and the telegraphic address "Gearing, Newcastle-upon-Tyne."

Mr. Devereux has arranged to relinquish his position as chairman and managing director of High Duty Alloys, Ltd., in order to devote himself to the scientific development and application of aluminium alloys over a wider commercial field than hitherto.

He will retain the chairmanship of International Alloys, Ltd., and expects to be in a position to announce his plans in more detail in the near future.

MICROCHEMISTRY
APPARATUS · METALLURGICAL APPLICATIONS · TECHNIQUE

BEFORE the war, much of our microchemical apparatus came from Germany. The analyst must inevitably ask himself what advances have been made in that country during the war years. And, since it is unthinkable that we should fall back once again to a position of dependence, the manufacturer of scientific apparatus, too, must be keenly interested. It would be natural to hope, and cheering to find, that some facilities existed for the inspection of German scientific apparatus by the British manufacturer. It would not be unreasonable if manufacturers of microchemical balances here had had the opportunity to examine the latest German balances for improvements, and if the same could be said for the makers of microscopes, spectrographs, colorimeters, polarographs, and other instruments in whose construction Germany was formerly widely held, rightly or wrongly, to be pre-eminent. Some enquiries along these lines, however, suggest that such an opportunity is non-existent. British scientific manufacturers, as the correspondence columns of the scientific press clearly show, are already badly handicapped through labour shortage. It would appear that a further handicap, in the restriction of information of first importance, is being applied in addition. We have very recently heard much of certain not insignificant contributions to the war effort made by scientists. Surely a high priority for the progress of science in peace is not too much to expect—or demand.

Chromatographic Methods in Inorganic Micro-Analysis

By J. H. Beaucourt and D. L. Masters

Chromatographic analysis is now a well-established technique in the field of organic chemistry, but its applications in the inorganic field still await development. The method has been applied chiefly in biochemical investigations, thus falling without the purview of the inorganic chemist. Consequently the possibilities of the technique in the inorganic field have tended to be overlooked, and, indeed, in our experience many inorganic chemists are unfamiliar with the methods. It has therefore been thought desirable, in the present paper, to indicate briefly the development and principles of the technique, before going on to describe how it may be applied to inorganic problems. Since chromatography, regardless of its field of application, is necessarily restricted to the manipulation of small quantities of material, it may be regarded essentially as a micro method.

CHROMATOGRAPHY was first used by Tswett, the Russian botanist, in the year 1906, for the investigation of plant and animal pigments. By its use, he was able to show for the first time that chlorophyll is not a single substance, but is a mixture of two compounds, α-chlorophyll and β-chlorophyll. This was demonstrated by chromatographing petroleum ether extracts of leaves, and finding that separation occurred in which several other components as well as the two types of chlorophyll made their appearance.

Although Tswett published details of his method in 1910, it was not till 1931, when the work of Kuhn and his co-workers on the carotenoid pigments was published, that the methods began to be applied extensively. This has been ascribed to the fact that since Tswett's work was published in Russian it was therefore unnoticed by many chemists. It is of interest to note, in passing, that separations have since been achieved by Kuhn and others, such as that of carotene, which were forecast as likely by Tswett, and, indeed, as probably being capable of achievement through chromatography.

The basic principles of chromatography may be described in a few words. If a solution of two coloured organic substances in an appropriate solvent is allowed to percolate through a column of a suitable adsorbent packed in a glass tube, in favourable circumstances it is possible to obtain selective adsorption of the two components, which, in consequence, separate out into two

distinct zones. The column may then be extruded, the zones separated, and each compound recovered by extraction with another solvent.

Details of the Process

In order to give a clearer picture of the method, the apparatus used, and some of the more important terms employed, an actual experiment will be described. In this will be studied the behaviour of two substances when chromatographed together, and then, as a contrast, treated singly.

It will be assumed that a separation is required of two substances, A and B, both of which are soluble in petrolcum ether. It will also be assumed that A is rather more strongly adsorbed on activated alumina than is B. A tube about 8 to 10 inches in length, and about $\frac{3}{4}$ in. diameter is chosen, and a slight constriction is made about 1 in. from one end, as is evident in Fig. 1. A filter plate is placed on the constriction, which is then covered with a thin layer of glass-wool or cotton-wool. The tube is inserted in a filter flask as shown.

Fig. 1.—Basic apparatus for chromatography.

Fig. 2.—A simple chromatogram.

Fig. 3.—The developed chromatograph.

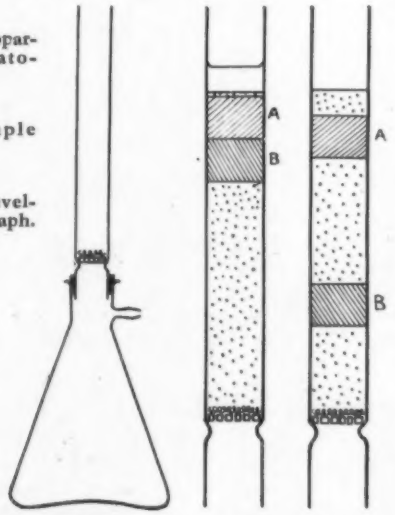


Fig. 1. Fig. 2. Fig. 3.

A slurry of activated alumina and petroleum ether is poured into the tube, and an intermittent vacuum applied to promote rapid settling. This is continued till the column of alumina is about 4 inches high, taking care throughout that the column is never sucked completely dry, as otherwise objectionable fissures may develop which will prevent satisfactory zoning in the later stages.

The petroleum ether solution of the two substances is allowed to percolate through the column, gentle suction being applied if necessary. Two zones will form, roughly as shown in Fig. 2, but at first the zones will probably be ill-defined. This is called the *chromatogram*. In order to effect a sharper separation the chromatogram is now *developed* by washing with further quantities of pure solvent. If this does not produce a satisfactory separation, a petroleum ether-benzene mixture (9 : 1) is employed, and in some cases it may be necessary to increase the proportion of benzene, or even to include other solvents, such as ether or acetone. Ultimately the zones will be separated out as indicated in Fig. 3.

After a satisfactory separation has been made, the glass tube is removed from the flask, and tapped gently with a piece of wood to loosen the column, which is then extruded by a wooden rod sufficiently narrow to pass through the constriction. The column is cut with a spatula, and the portions containing each component are *eluted* with appropriate solvents.

If the experiment is repeated, using a solution of B alone, followed by a solution of A, the zone formed in the first place by B will be displaced by A, and will migrate further down the column. If, on the other hand, the solution containing A is first passed through the column, followed by that containing B, A will not be displaced down the column in this way. Instead, B will pass through the zone formed by A, and will form its own zone further down.

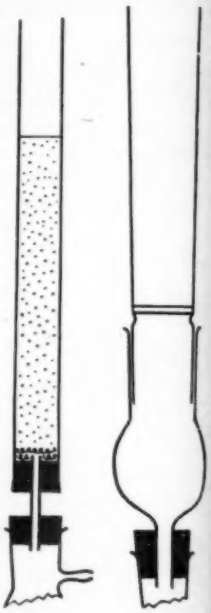


Fig. 4. Fig. 5.

Figs. 4-5.—Two types of apparatus for chromatography.

Apparatus

Many different forms of apparatus have been used for chromatography, but in general little is to be gained by using complicated arrangements. The apparatus shown in Figs. 4 and 5 is primarily for carrying out normal separations, and is self-explanatory from the diagrams. In one of the tubes removal of the column is facilitated by having a slight taper on the tube from bottom to top. In other diagrams some of the forms devised for handling extremely small quantities, referred to therefore as micro-chromatographic apparatus, is depicted. The tube (Fig. 6) is due to Hesse[1] and has a combined plunger and support made from glass rod. That in Fig. 7, by Becker and Schoff,[2] contains absorbent packed in the narrow part of the tube, while the solution is contained in the wider portion. The whole is stood on a sintered glass plate attached to a suction flask. The tube described by Willstaedt and With,[3] and shown in Fig. 8, also uses a glass rod support and plunger of rather a different pattern from that of Hesse. The capillary tube terminating in a funnel (Fig. 9) has been described by Schwab and Ghosh[4] for inorganic work, where, as will shortly be seen, there is not the same necessity to extrude the column.

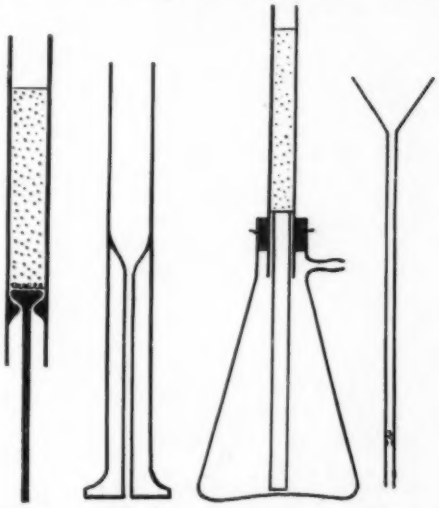
Tubes which can be taken apart have been described.[5] In certain cases the separation has to be conducted in an inert atmosphere, and apparatus for this purpose,[6] and also for heating or cooling the column[6,7] is available.

Adsorbents

Activated alumina is perhaps the most widely used adsorbent. Other adsorbents which find applications in

[1] Hesse, *Angew. Chem.*, 1936, **49**, 315.
[2] Becker and Schoff, *Liebig's Ann.*, 1936, **524**, 124.
[3] Willstaedt and With, *Z. Physiol. Chem.*, 1938, **253**, 40.
[4] Schwab and Ghosh, *Angew. Chem.*, 1940, **53**, 39.
[5] Bekesy, *Biochem. Z.*, 1942, **312**, 100.
Crowell and Konig, *Ind. Eng. Chem., Anal. Ed.*, 1944, **16**, 347.
[6] Ralston, Harwood and Pool, *J. Amer. Chem. Soc.*, 1937, **59**, 986.
[7] Kuhn and Ströbele, *Ber.*, 1937, **70**, 773.

special cases are calcium carbonate, magnesium oxide, fuller's earth, silica gel, sucrose, sodium sulphate. With certain adsorbents, the compound can be recovered in unorthodox ways. For example, sucrose can be dissolved in water, or magnesium oxide in hydrochloric acid, and the compound extracted with an immiscible solvent.



Pig. 6. Fig. 7. Fig. 8. Fig. 9.

Figs. 6–9.—Four types of ayparatus for micro-chromatography.

A method for a preliminary search for suitable adsorbents has been described by Crowe,[8] who recommends that a number of different adsorbents should be placed in the depressions in a spot plate, a drop of the solution under investigation being then allowed to flow from the rim of each depression down into the adsorbent. When a suitable combination has been found, a wedge-shaped " column " may be formed by placing a slurry of the adsorbent in a Petrie dish, and allowing this to settle while the dish is slightly tilted. Separations can then be carried out on very small amounts of solution by permitting the solution to percolate from the narrow edge of the wedge.

Brown[9] recommends blotting paper as capable of giving separations. In his method a sheet of the paper, a moderately hard blotting paper, is placed between sheets of plate glass, of which the top one has a small hole in the centre. The solution is added through this hole, and subsequently the required amount of developing solvent is also added. Such a chromatogram may easily be examined, and, if required, can afterwards be filed. The use of filter paper has also been recommended by other authors[10,11] in the form of strips which are dipped into the solution under investigation so that it is drawn up through the strip by capillary attraction. Strips of this type are particularly recommended for subsequent examination by ultra-violet light.

Colourless Substances

So far we have implicitly considered coloured substances, where the separation into zones is clearly visible. Several methods are available for dealing with colourless substances, among which may be mentioned examination of the column in ultra-violet light, when, if the substances fluoresce, the zones can be recognised, and treatment of the column with a suitable reagent. This is applied by brushing the column throughout its length with a small brush dipped in the reagent. For example, benzidine may be detected by the application of a solution of lead peroxide in acetic acid. A blue streak forms to mark the zone. Recently[12] higher fatty acids have been separated on a magnesium oxide column impregnated with phenol red. The zones appear as yellow bands in the column.

If none of these methods is successful, the method of *liquid chromatograms* may be employed. The column is copiously washed with the solvent, and the washings are collected in fractions which are examined until no further elution occurs. Development is continued, using more active developers in the following order: petroleum ether-benzene, benzene-ether, ether-acetone and so on, using methanol, pyridine and acetic acid. In favourable cases the first solvent may wash the compounds selectively out of the column, and it is not generally necessary to continue beyond two or three solvents or mixtures. The method is, however, obviously laborious, since each fraction has to be distilled and examined.

Behaviour of Organic Compounds

It is of interest to note that the most strongly adsorbed organic substances are the acids, possessing the active —COOH group. These are followed by alcohols, ketones, esters and ethers, unsaturated hydrocarbons, aromatic hydrocarbons, and finally aliphatic hydrocarbons.

Unsaturated compounds containing conjugated double bonds are more strongly adsorbed than others. The adsorption is more pronounced the greater the number of double bonds. Similarly with aromatic hydrocarbons, those with the largest number of rings are most strongly adsorbed.

This accounts for the diverse behaviours of the various solvents. Thus benzene tends to displace adsorbed substances more readily than petroleum ether, so that a solute will not be so strongly adsorbed, and a zone will not be as strongly fixed from benzene as it will from petroleum ether. On the other hand, benzene is more useful in developing the zones. The action of the other solvents, ether, acetone, ethanol, is similarly explained, since they tend to be more strongly adsorbed than benzene in that order.

Inorganic Chromatography

The main work in this field has been carried out by Schwab and his associates[13] and by Erlenmeyer and his co-workers.[14] Both activated alumina and ordinary dehydrated aluminium hydroxide have been found to be effective adsorbents, and are preferable to others such as magnesium oxide, barium sulphate and zinc oxide. Since the zones formed are not always clearly defined, their recognition is facilitated by development with a suitable reagent which forms coloured products. Thus, many heavy metal ions can be developed with ammonium sulphide to give black sulphide zones; and iron, copper and cobalt react with potassium ferrocyanide to give blue, brown and greenish zones respectively.

[8] Crowe, *Ind. Eng. Chem., Anal. Ed.*, 1941, **13**, 845.
[9] Brown, *Nature*, 1939, **143**, 377.
[10] Bugyl, *Koll. Z.*, 1938, **84**, 74.
[11] Hensley, *J. Phys. Chem.*, 1940, **44**, 1071.
[12] Graff and Skan, *Ind. Eng. Chem., Anal. Ed.*, 1948, **15**, 340.
[13] Schwab and Jockers, *Naturwiss.*, 1937m **25**, 44; *Angew. Chem.*, 1937, **50**, 546; Schwab and Dattler, *ibid.*, 691; 1938, **51**, 709; Schwab and Ghosh, *ibid.*, 1939, **52**, 666; 1940, **53**, 39.
[14] Erlenmeyer and Dahn, *Helv. Chim. Acta*, 1939, **22**, 1369; Erlenmeyer and Schoenauer, *ibid.*, 1941, **24**, 878.

A solution of lead, silver, zinc, cadmium and manganese nitrates, when chromatographed and developed with ammonium sulphide, gives the following zones :—

Pb^{++}	Black.
Ag^{+}	Grey.
Zn^{++}	White.
Cd^{++}	Yellow.
Mn^{++}	Flesh-colour.

From an aqueous solution the commoner cations separate in the following order :—

As^{+++}
Sb^{+++}
Bi^{+++}
Cr^{+++} Fe^{+++} Hg^{++}
UO_2^{++}
Cu^{++}
Ag^{+}
Zn^{++}
Co^{++} Ni^{++} Cd^{++} Fe^{++}
Tl^{+}
Mn^{++}

The ions shown on the same line cannot be separated directly from aqueous solution, since they form mixed zones, and other methods have to be devised for this purpose.

If the metals are converted to amine or tartrate complexes, the order of adsorption can be altered, and separations effected which are impossible with the simple ions. Thus, in ammonia solution cobalt and nickel can be readily separated, and similarly in tartrate solution iron and chromium form distinct zones, whereas in aqueous solution, it will be noted, separation is not achieved.

The method has limitations for the separation of anions, mainly because of the difficulty of forming characteristic coloured compounds with the colourles anions. Nevertheless, a definite separation series can be obtained, and the separation of certain small groups can be readily accomplished.

For example, chromate and chloride can be developed with silver nitrate after adsorption. A yellow band forms at the top, and an orange coloured band below it, due to chromate and dichromate respectively. On exposure to light a violet zone forms below the orange band, due to decomposition of the silver chloride. Similarly, ferricyanide and chloride can be differentiated.

Inorganic Applications

As an example of the possibilities of the method in microanalysis, it is possible to detect 1μg. of ferric iron in the presence of 10,000 times that amount of copper or cobalt, by development with ferrocyanide. Similarly, 1 μg. of copper can be detected in the presence of excessive quantities of cobalt or cadmium.

It has been shown that the length of a zone is a measure of the amount of adsorbed substance, and hence the method has possibilities in quantitative or semi-quantitative work.

A more recent development in this work is due to Erlemeyer and Dahn.[15] Using 8–hydroxyquinoline as "adsorbent," they found that a series of ions gave zones in the following order :—

VO_3^{-}	Dark grey.
WO_4^{--}	Yellow.
Cu^{++}	Green.
Bi^{+++}	Yellow.
Ni^{++}	Green.
Co^{++}	Reddish.
Zn^{++}	Yellow
Fe^{+++}	Black.
UO_2^{++}	Orange.

This is not a case of true adsorption, but rather of selective chemical combination.

In later work[16], the organic reagent was deposited on kieselguhr or barium sulphate, from solution. In addition, violuric acid was used to form a column, and was found suitable for potassium, ammonium, sodium, magnesium, barium, strontium, calcium, copper, mercury and lead. Potassium-ammonium and barium-strontium mixtures were not separated by this method, but other pairs yielded to the treatment, as did a mixture of potassium, sodium, calcium and magnesium.

In an attempt to place the method on a quantitative basis, a mixture of sodium and potassium acetates was chromatographed in a tube packed with starch and violuric acid at its lower portion, and with starch and 5–oxo–4–oximino–3–phenyliso–oxazoline above it. The potassium was retained in the upper portion of the column as a yellow zone, whilst the sodium formed a red zone in the lower portion. With low concentrations of sodium, quantitative estimations gave an accuracy of 5 per cent.

It will be appreciated that this work has great possibilities, since many other organic reagents await investigation as "adsorbents."

[15] Erlenmeyer and Dahn, *loc. cit.*
[16] Erlenmeyer and Schoenauer, *loc. cit.*

The Detection of Vanadium

As little as 4 mg. of vanadium, in the form of vanadate, may be detected by a spot test which is reported to be specific.* The test is carried out on a spot plate, one drop of test solution mixed with one drop of 85 per cent. phosphoric acid being allowed to stand for a few seconds, and then treated with one drop of ten per cent. sodium tungstate. A colour varying from yellow to orange is positive for vanadate. Reducing agents, strong acids and hydrogen peroxide interfere with the test, and the presence of coloured ions may make it less sensitive, but very small amounts of the ion may be detected in the presence of large amounts of many other ions.

1 G. Ashburn and J. H. Reedy, *Ind. Eng. Chem., Anal. Ed.*, 1945, **17**, 63.

Non-Ferrous Metals Control

The Ministry of Supply has announced that, as from May 11th, applications to the Non-Ferrous Metals Control for licences to acquire copper and zinc for United Kingdom consumption will be considered by the Control without restrictions in respect of the type of article to be manufactured. Certain restrictions on the release of copper and zinc will, however, continue to be imposed as regards export orders.

Applicants should note that the statutory provisions regarding the acquisition and disposal of these metals are still in force and that the present procedure of submitting to the Non-Ferrous Metals Control, Grand Hotel, Rugby, schedules of orders with applications for licences, must be followed.

Effect of Notches on Strength of Heat Treated Low Alloy Steels

(A Composite)

AT the Twenty-sixth Annual Convention of the American Society for Metals held in October, 1944, two papers were presented, dealing with the effect of notches on the strength properties of low alloy steels. Both papers dealt with work carried out under the auspices of the International Nickel Company, and form the fifth and sixth reports on the results obtained in such investigations.

The first paper by G. Sachs, J. D. Lubahn and L. J. Ebert, concludes a series of investigations on the factors which determine the notch strength properties of heat-treated low alloy steels at room temperature, and opens with a summary of the conclusions which have been drawn from the work of the authors and others on the influence of notches of various depths on the strength properties of metals. The results are then given of an investigation on the relationship existing between the notch-strength, notch-depth and notch-radius and of the laws governing the fracture stress of unnotched and notched test bars.

The investigation was made on a steel containing 0·35 to 0·45% carbon, 1·0 to 1·5% nickel and 0·45 to 0·75% chromium (S.A.E. 3140). The combined effects of depths and radius of notch were determined on test specimens with notches having depths of 15, 30, 50, 65, 80, and 90% notch, and radii of 0·000, 0·008 and 0·031 inch, heat-treated by oil-quenching from 830° C. and tempering at various temperatures from 260° to 540° C. to give various tensile strengths within the range 65 to 110 tons per sq. in.

The results obtained show the "notch strength" to increase with notch depth almost linearly, only if the strength of the steel was at the lower end of the strength range (70 tons per sq. in.), or if the radius of the notch was large. Test specimens with a sharp notch, 0·000 radius, yielded a relationship very closely approaching a value of twice the tensile strength for a 100% notch. The larger notch radius, 0·031 inch, affected the notch strength only very slightly, up to a notch depth of approximately 75%. For deeper notches, however, the notch strength increasingly deviated from that for sharply notched specimens, exhibiting a flat maximum at a notch depth of approximately 85%. In general the results show that the notch strength ratio can be represented by a single family of curves, the same curve applying to a sharply notched steel of somewhat low strength, and to a high strength steel, provided with a well rounded-off notch.

The investigation also makes possible the separation of the two fundamental effects occurring in notch bar tensile (and bending) tests, viz., that of triaxiality and that of stress concentration. The cohesive strength of a heat-treated steel increases with increasing triaxiality, only slightly less rapidly than the flow stress (shear stress), confirming McAdam's conceptions. The closeness of these two relations accounts for the rapid changes from a ductile to a brittle condition, which may be caused by rather small changes in metal structure or in the method of applying the load.

In the second paper, the same Authors, together with E. L. Aul, give the results of an investigation on the effect of fibre on notched bar tensile strength properties of a heat-treated low alloy steel. Regular and notched bar tensile tests were made on specimens taken in both the longitudinal and transverse directions from 1½ and 2¾ inch diameter, hot-rolled rod of an alloy steel similar to that used in the previous investigation. Most of the test specimens were heat-treated by oil quenching from 830° C. and suitable tempering to give a tensile strength approximating to 85 tons per sq. in., but some transverse tests were made on specimens heat-treated to 62 and 100 tons per sq. in. respectively.

The results obtained show that the rod size and location of the specimens had little effect on the results of either the regular or the notched bar tensile tests in the longitudinal direction, but that in the transverse direction the ductility was considerably less than in the longitudinal direction. In the regular tensile tests, ductility was lower in the 2¾ in. diameter rod than in the 1½ in. diameter rod. In the same tests the difference between the longitudinal and transverse ductilities increased considerably with increase in strength, from a difference of approximately 40% of the longitudinal values at 55 tons per sq. in., to a difference of 80% at 110 tons per sq. in. for test specimens from 1½ in. diameter rod. In the notch bar tensile tests, however, ductility was lower in the 1½ in. diameter rod than in the 2¾ in. diameter rod. Neither size of rod or fibre direction had any effect on the ultimate tensile strength.

The relation between strength level and transverse notch strength was investigated for 1½ in. diameter rod. The effect of eccentricity on the notch strength increased with increasing strength level, yielding a family of notch-strength ratio versus eccentricity curves, similar to those of longitudinal test bars. A transverse curve of such a type for a certain strength level corresponded to that of a longitudinal curve for a higher strength level. Identical values, however, of notch-strength ratios in the transverse and longitudinal directions respectively, occurred at values of strength level that were more nearly equal for concentric than for eccentric specimens. The notch strength of the concentrically tested transverse specimens remained the same as that of longitudinal specimens up to a strength level of approximately 70 tons per sq. in. With increasing strength level, however, the transverse notch strength became increasingly smaller than the longitudinal and at a strength level of 100 tons per sq. in., the transverse notch strength of concentric specimens was only approximately 80% of the longitudinal notch strength. The concentric tests showed no difference between the transverse notch strength of 1½ in. and 2¾ in. diameter rod

1 *American Society for Metals*, 1944, Preprint No. 15, pp. 1–23.
2 *American Society for Metals*, 1944, Preprint No. 14, pp. 1–13.

heat-treated to a strength level of 84·5 tons per sq. in.

It has been shown in the first paper that the notch ductility of concentric specimens is nearly a linear function of the eccentric notch strength for a suitably selected eccentricity of say ¼ in., and this generalisation is further supported by the results of the second investigation which show a similar effect of rod size and direction of testing on the notch ductility, as measured either by the eccentric notch strength or the concentric notch ductility. With ¼ in. eccentricity, the transverse notch strength was approximately 65% of the longitudinal notch strength for the 2¾ in. diameter rod and only 50% for the 1½ in. rod.

Segregation of Molybdenum in Phosphorus-Bearing Alloyed Cast Irons

By F. B. Rote and W. E. Wood

IN a previous investigation, a number of castings made under ordinary foundry conditions were found to be pearlitic, although they were alloyed to an extent which would normally have given an acicular structure. In conjunction with the pearlitic structure, the mechanical properties were lower than anticipated and the castings were unable to meet high strength specifications. Detailed analysis of the castings showed that the composition differed in only one significant particular from irons known to give an acicular structure and that was in the phosphorus content. An investigation was, therefore, carried out to determine the influence of phosphorus on the solidification and austenite transformation characteristics of grey cast iron, both plain and alloyed with nickel and molybdenum.

The base irons selected for the investigation contained 2·65% total carbon, 2·25% silicon, 1·2 manganese, 0·03% sulphur and 0·016 to 1·83% phosphorus. A series of unalloyed irons was cast without additions, while others were alloyed with 1·75% nickel and 0·75% molybdenum. The irons were made in 30 lb. melts in an Ajax induction furnace from charges consisting of wash metal, low carbon steel punchings, ferro-alloys, nickel and coke. All melts were heated to 1510° C. and poured at 1455° C. Phosphorus was added to the irons in the form of ferro-phosphorus containing 24% phosphorus, and the furnace charges were adjusted to compensate for changes in the alloy charged for low- or high-phosphorus contents by changes in the quantity of steel punches charged. The chemical composition of the different irons is given in Table I.

A number of different castings were made from each heat, but for the purpose of the investigation, only one is considered—a solid cylinder, 3 in. diameter by 4·5 in. in length. This casting was made in an open top core mould and was poured directly from the induction furnace. After the casting was poured and skimmed, a calibrated platinum thermocouple, sheathed in a thin wall quartz tube and centred by means of a disc, was inserted to the geometric centre of the molten iron. As soon as the thermocouple reached the temperature of the molten iron, the first temperature reading, usually about 1345° C., was made on a precision pyrometer, and thereafter readings were taken each ten seconds until the castings had cooled below the pearlite transformation temperature in those irons which underwent a pearlite transformation, and to 205° C. in the acicular irons.

American Society for Metals, 1944, Preprint No. 35, pp. 1-24.

TABLE I.—COMPOSITIONS OF UNALLOYED AND NICKEL-MOLYBDENUM-ALLOYED GREY CAST-IRON.

Heat No.	T.C.	C.C.	Si	Mn	Ni	Mo	S	P
1	2·61	0·59	2·24	1·19	1·79	0·77	0·03	0·016
11	2·59	0·61	2·29	1·20*	1·75*	0·75*	0·03*	0·14
8	2·64	0·63	2·29	1·20*	1·75*	0·75*	0·034	0·34
12	2·63	0·67	2·21	1·20*	1·75*	0·75*	0·03*	0·45
5	2·66	0·63	2·23	1·20*	1·75*	0·75*	0·03*	0·58
14	2·64	0·65	2·26	1·22	1·77	0·76	0·29	0·77
7	2·61	0·67	2·31	1·20*	1·75*	0·75*	0·03*	0·95
2	2·64	0·66	2·22	1·20*	1·75*	0·75*	0·03*	1·25
10	2·63	0·69	2·25	1·20*	1·75*	0·75*	0·03*	1·83
31	2·65*	—	2·25*	1·22	—	—	0·032	0·018
32	2·66	—	2·21	1·20*	—	—	0·03*	0·37
33	2·65*	—	2·25*	1·20*	—	—	0·03*	0·93
34	2·68	—	2·25*	1·20*	—	—	0·03*	1·80*

* Calculated Analysis.

Cooling curves were obtained for all the castings. A micro examination was made of the structures developed in the castings and the formation and character of the phosphide eutectic studied.

The results obtained from the various tests showed that in alloy cast iron containing nickel and molybdenum of the compositions investigated, molybdenum formed a complex quaternary eutectic with phosphorus, iron and carbon. The composition was such that for each unit of phosphorus above the amount soluble in iron, 0·12%, 1·3 units of molybdenum were removed from the matrix. The composition of the eutectic which formed as small pellets on the surface of the cast cylinder was 2·10% carbon, 1·1% silicon, 1·65% nickel, 4·40% phosphorus, 5·85% molybdenum and the remainder iron.

In low-phosphorus, molybdenum-alloyed cast iron (0·12% phosphorus), the eutectic composition probably approximated closely to that given above, but unless the molybdenum content exceeded 1·3, practically all the molybdenum was present in the phosphide and the molybdenum content of the phosphide was limited by the availability. As a consequence of the molybdenum segregation, a pearlite structure might be obtained in a molybdenum-alloyed iron, although the average alloy content was such as to yield an acicular type of structure.

The diffusion of molybdenum to the phosphide eutectic was found to take place on cooling between solid austenite and liquid phosphide at a point between their respective solidification temperatures. On reheating, however, the reverse reaction did not take place. On remelting a nickel-molybdenum iron with high phosphorus content, it was found that the eutectic melting temperature approached that of unalloyed cast irons, due to the failure of the molybdenum to rediffuse to the solid austenite. Attempts to control the structure of high-phosphorus alloyed irons by compensatory molybdenum additions were only partiall successful, due to a pearlitic envelope surrounding the phosphide eutectic.

In general, the results obtained from the investigation showed that, from a practical standpoint, the addition of small quantities of molybdenum to an ordinary grey iron in which no attempt was made to keep the phosphorus low, was useless because practically all the molybdenum segregated to the phosphide eutectic.

Magnesium Alloy Forgings

By A. L. Rustav, F. B. Rote and C. E. Wirsing

A WAR-TIME development of outstanding post-war significance is the improvement in the methods of making magnesium alloy forgings, whereby forgings of better quality and of greater design possibilities than were previously available can now be produced. The results are given of research work which had two primary objectives: (1) To produce and test, under static and dynamic conditions, a number of forgings from standard forging alloys to obtain data upon which designers can base calculations in considering the application of magnesium forgings to replace heavier metals; (2) to obtain data on the forgeability of the standard American forging alloys.

In Table I are given the specified composition and mechanical properties of the five common forging alloys. In hammer forging operations, the AM 3 S, AM 52 S, and AM 65 S alloys handle very much the same, while AM 57 S is more difficult to forge and AM 58 S the most difficult to forge. The relative forgeability of the three classes of alloys; the three lower strength alloys being represented by AM 3 S, and AM 57 S and AM 58 S, representing the other two classes, were determined on a piston by a production cycle of three operations: Upsetting to the diameter of the piston forging, blocking with the wide radii on all corners and edges, and finishing. In this series of experiments three definite procedures were used: (1) All three operations in the hammer; (2) Upset and block in the press and finish in the hammer; (3) Upset, block and finish in the press.

Because of the unique crystallographic structure of magnesium alloys, certain of the conventional forging operations cannot be performed, or must be performed, if at all, under carefully controlled conditions. When magnesium alloys are extruded, the crystals become oriented with respect to the axis of extrusion, the basal planes becoming perpendicular to the axis, and the slip planes are, therefore, oriented perpendicular to the desired direction of deformation during a process requiring elongation along the original axis. Operations such as rolling or fullering, therefore, may not be used in the production of magnesium forgings and all hammer operations must be confined to finishing after the metal movement from the rough multiple has been achieved in a press.

In production, many forgings require multiple operations, which necessitate cooling the metal after the first operation and then reheating for subsequent operations, but this procedure has not been successful in the manufacture of magnesium alloy forgings. Reheated forgings have been found to crack badly transverse to the original grain flow in the forging stock. It is desirable, therefore, to complete the forging operation on a multiple in one heat, and if this cannot be done, the first operation after a reheat should be performed at a relatively slow rate of work. The forging die temperatures should be maintained at a level giving a suitable balance between forging temperature, forging rate and die temperature, so that a certain amount of cold work may be introduced into the finished forging, thus giving superior properties. No comprehensive investigation of this factor has been completed, but indications show that the finishing dies should be maintained at about 205° C. (400° F.) in a hammer finishing operation.

In forgings made to date, a number of heat-treating procedures have been used, including direct ageing after forging, water quenching from the die plus ageing, or quenching and ageing after air cooling from the die. Variable times and temperatures for the solution treatment or ageing treatments have been used. Where the maximum room temperature properties are desired, an ageing treatment of about 16 hours at 152° C. preceded by a direct quench from the hammer or press produces the maximum stress in the AM 58 S alloy, and for high temperature applications in which a coarse grain is more desirable, a quench and age-treatment may be used. Adequate solution with a minimum, although appreciable, grain growth is achieved in 2 hours at 370°. After solution treatment, the alloys can be aged for 16 hours at 152° C., Table I.

One of the difficulties in the production of magnesium forgings is in obtaining a clean trim, free from tearing and shearing, and experiments have been conducted to determine the most favourable trimming temperature on a number of forgings. In each experiment, each of the five standard forging alloys has been included and trimming temperature ranges have been determined. The trimming temperature range is about 150° to 230° C. for AM 3 S alloy and 175° to 260° C. for the AM 58 S alloy. The other three alloys have intermediate trimming temperature ranges.

TABLE I.—CHEMICAL COMPOSITION AND SPECIFIED AND TYPICAL PROPERTIES OF STANDARD MAGNESIUM ALLOY FORGINGS

Designation		Composition						Physical Properties.							
								Yield Stress (0·1%) Tons per sq. in.		Tensile Strength Tons per sq. in.		Elongation %		Compression Yield	Brinell Hardness
Amer. Mag.	Dow	Al	Zn	Sn	Si Max.	Mn Max.	Other Metals Max.	Typical	Specified Min.	Typical	Specified Min.	Typical	Specified Min.		
AM 3 S	M–1	—	—	—	0·3	1·2	0·3	16·7	5·4	22·9	18·6	7	2	—	47
AM 52 S	FS–1	2·5/3·5	1·3 Max.	—	0·3	0·1	0·3	17·8	14·0	24·9	22·4	15	11	—	50
AM 57 S	J–1	5·8/7·2	0·4/1·5	—	0·3	0·15	0·3	17·1	14·0	26·7	24·1	12	6	8·1	57
AM 58 S	O–1	7·8/9·2	0·8 Max.	—	0·3	0·13	0·3	20·5	15·2	29·2	18·7	10	5	9·8	65
AM 58 S Aged *	O–1	7·8/9·2	0·8 Max.	—	0·3	0·13	0·3	21·7	17·8	30·6	26·7	6	2	11·6	72
AM 58 S Q.+ A.*	O–1	7·8/9·2	0·8 Max.	—	0·3	0·13	0·3	21·7	—	31·8	—	6	—	10·7	72
AM 65 S	D–1	5·0/4·0	—	4·0/6·0	0·3	0·4	0·3	14·0	12·8	24·1	22·3	12	6	—	52

* Solution Treatment 2 hours at 370° C.F. followed by water quenching.
Age Treatment 16 hours at 152° C.

Metals and Alloys, 1945, Vol. 21, No. 3, pp. 688-694.

Rates af Tempering in Cobalt Steels

By E. A. Loria

THE results are given of a study of the effect of cobalt in the tempering of plain carbon—cobalt steels by interpretation of hardness measurements. The tests were carried out on

American Society for Metals, 1944. Preprint No. 4, pp. 1–8.

five steels, Table I, on discs of ½-in. diameter and from ⅛ to ¾-in. thickness. No specimens greater than ½-in. were used for steels D and E because of the necessity of obtaining martensite on quenching. The steels were austenized by heating steels A, B, and C in a lead bath and steels D and E in an electric resistance furnace and quenching in brine. Tempering was carried out over a range of temperature varying from 250° to 710° C., and Rockwell C hardness measurements were made according to standard technique.

The results obtained show that the hardness of plain carbon cobalt steels tempered over the range 250° to 710° C was similar to that of plain carbon steels tempered over the same range. The cobalt present promoted a small increase in hardness after tempering by solid solution hardening of ferrite. A 7·4% cobalt steel show a very slight secondary hardening in the range 275° to 385° C. and this effect was very small compared to that found in high speed steels and it was not observed in an 11·2% cobalt steel.

TABLE I.—COMPOSITION OF STEELS TESTED.

Steel	Composition						Austenising Tem. Deg. C.
—	C	Co	Si	Mn	S	P	—
A	0·76	Nil	0·42	0·26	0·026	0·026	860
B	0·71	1·95	0·42	0·26	0·026	0·026	860
C	0·71	4·20	0·42	0·29	0·026	0·026	880
D	0·68	7·40	0·43	0·26	0·026	0·026	960
E	0·68	11·20	0·42	0·26	0·026	0·026	960

Soldering with Tin-Lead Alloys

By A. Z. Mample

AN engineering approach to soldering with tin-lead alloys is made by considering the characteristics of the various tin-lead alloys, the right procedure in the application of these alloys, an understanding regarding the functions of a flux, the relative characteristics of various metals to "take" solder, technique as a function of metal flow and the strength of a soldered joint under various conditions of load and temperature.

TABLE I.

MELTING RANGE DATA OF TIN-LEAD ALLOYS

Composition		Temperature Limits		Pasty Temperature Range ° F. above the Solidus Point
Tin	Lead	Lower Solidus ° F.	Upper Solidus ° F.	
0	100	621	621	0
10	90	500	570	70
20	80	361	531	170
30	70	361	496	135
40	60	361	460	99
45	55	361	438	77
50	50	361	421	60
60	40	361	375	14
62	38	361	361	0
70	30	361	370	17
80	20	361	399	38
90	10	361	423	62
100	0	450	450	0

Melting range data for tin-lead alloys given in Table I, show the different temperatures at which the various alloys change from one state to another and the temperature range of the "pasty" or semi-liquid state. A 45/55 solder has a semi-liquid range of 77° F. and this range is equivalent to a time period, for it means that a period of time must elapse long enough for the solder and the article soldered to cool correspondingly to a drop in temperature of 77° F. From a study of various data, it is recommended that the eutectic composition be accepted as 62% tin, 38% lead, and the eutectic melting point as 361° F. The low-tin solder, 20% tin, 80% lead, adopted for general soldering purposes as a war-emergency measure, has a semi-liquid range of 170° F. Inasmuch as the solidus points of the 45/55 and the 20/80 solders are the same, the critical cooling-off period of the latter is greater than the former and this constitutes the main objection to the use of the lower tin content alloy.

Low-tin alloys do not require more heat merely because they have high liquidus points as tin poor alloys require less B.Th.U's per lb. of metal, Table II, to raise them 100° F. above their relatively higher liquidus points than tin-rich alloys do when raising the latter 100° F. above their lower liquidus points.

Three factors which affect the facility with which soldered joints can be made are: (1) the characteristic or ability of the metal to be wet by the liquid solder and to alloy with it, (2) the surface coatings which tend to resist soldering and (3) the relative ability of metals to conduct heat. The relative solderability of certain base metals arranged in the descending order of their solderability are: silver, copper, brass or bronze, tin, lead, nickel-silvers, zinc, cadmium, iron, and steel. Although such an order is frequently used by designers, when soldering to base metals, it is often ignored when metals are to be plated, such as where improvement of a base metal is necessary for appearance purposes and to improve its solderability. An example of this is cadmium plating. Electroplated metal coatings, also, are in general not so good to solder to as are hot-dipped metal coatings. In Table III the effect of coatings in some cases on the strength of soldered joints is shown. Surface coatings on metals which, resisting soldering, are either "made" coatings, such as enamel or varnish, or

TABLE II. SPECIFIC, LATENT AND TOTAL HEAT OF TIN-LEAD ALLOYS—B.Th.U's per Lb.

Composition		Mean Specific Heat		Latent Heat of Fusion	Total Heat in Liquid at 100° F. Above Liquidus, B.Th. U
Tin	Lead	60°F. to Liquidus	Liquid		
100	—	0·069	0·060	24·9	37·8
69·5	30·5	0·0579	0·0516	30·6	53·76
50	50	0·031	0·046	23·0	45·65
37	63	0·044	0·041	14·8	43·3
28	80	0·0394	0·0376	16·2	38·5
0	100	0·032	0·032	9·9	31·1

TABLE III. BREAKING STRENGTH OF LAP JOINTS—JOINTS WITH FILLETS.

Metal or Alloy	Sheet Thickness, In.	Lap Joint	Sq. In. (Joint)	Breaking Load, Lbs.		Average Number of Tests
				50/50	20/80	
Copper	0·094	Single	0·56	1750	1700	4
Brass	0·063	"	0·56	2570	2680	4
Iron (Black)	0·062	"	0·56	2100	2120	4
Copper	0·094	"	0·28	1310	1190	4
Brass	0·063	"	0·28	1450	1450	4
Iron (Black)	0·062	"	0·28	1400	1320	4
Iron (Galv.)	0·065	"	0·28	1370	1240	4
Iron (Tinned)	0·032	"	0·28	1070	1010	4

Metals and Alloys, 1945, Vol. 21, No. 3, pp. 702–707

natural coatings such as oxides, sulphides or carbonates of the base metal. Some of the latter are easily removed by use of a proper flux while soldering, while others are more troublesome.

Flux action is important in soldering. For a good overall flux, the flux residue must be non-corrosive, non-conducting (electrical) and non-hygroscopic. In addition, a flux should not readily decompose, volatilise or carbonise at normal soldering temperatures. Rosin which is generally considered a poor flux, if handled properly, particularly as regards heating, may function as the perfect flux so far as electrical applications are concerned. Acid or salt, the wax, and paste type fluxes are also used in soldering and have certain advantages and disadvantages for particular applications and parts.

Mechanical strength considerations in soldering should be evaluated even though no mechanical load is involved. Where elevated temperatures are involved, the solidus temperature provides a better guide as to the probable action of a specific solder than does the liquidus point. Short time loads may be applied to soldered joints with perfect assurance if applied correctly, but continuous loads require careful consideration of all factors relating to the strength of soldered joints. In general tin-lead alloys impart variable strength to joints. While the 50/50 alloy is somewhat stronger than the 20/80 alloy, the difference is not appreciable, Table III. The eutectic alloy, 63/38, may be taken as having the maximum strength of all tin-lead alloy. Lower strengths are obtained with alloys containing over 68% tin and under 20% tin.

Fatigue Tests on Some Copper Alloys in Wire Form

By H. L. Burghoff and A. L. Blank

THE results are given of a series of rotating-arc fatigue tests upon several copper alloys in the form of hard drawn-wire. The materials included four brasses, two copper-tin alloys, two tin bearing brasses, two silicon bronzes, four copper-nickel alloys and two age-hardened and drawn alloys containing copper, nickel and phosphorus. They were prepared and tested in the form of wire, 0·072 in. in diameter and most of the alloys were finished in commercial hard and spring tempers, that is as drawn 60 and 84% respectively after the last annealing. As all the alloys were drawn in coil form, it was necessary to straighten them mechanically before testing. Fatigue test data was given in S–N curves carried out to 100 million cycles or reversal of stress and the endurance limits of some of the alloys given in Table I are the values of stress taken from the curves at 100 million cycles.

Of the numerous wire materials tested, several were found to have endurance limits ranging from approximately 15·0 to 24·0 tons per sq. in. at 100 million cycles. In the brasses the ratio of endurance limit to tensile strength decreased substantially as the zinc content increased and only small additions of tin in tin-bronze were required to obtain a relatively high endurance limit. In the tin-bearing brasses, the resistance to fatigue was increased by the tin, but to a much greater extent in the 80-20 alloy than in the 70-30 alloy. Silicon, like tin, markedly increased the endurance limit of copper, the 3% silicon bronze appeared to be but slightly, if at all, inferior to the 4·37% tin bronze wire. Nickel also increased the fatigue resistance of copper, and the alloy containing 23% nickel had an endurance limit considerably higher than either the 80-20 or 70-30 alloys. The age-hardened and severely drawn copper-nickel-phosphorus alloy, showed particularly good properties.

In general, all the results obtained indicated the feasibility of several alloys, high with respect to endurance strength, but low with respect to content of critical alloying elements as compared with the commonly used phosphor bronzes. An approximate relationship between the ratio of endurance limit to tensile strength and the ratio of yield strength, as variously determined, to tensile strength appeared to exist for the various alloys tested.

TABLE I. COMPOSITION, TEMPERS AND PROPERTIES OF SOME OF THE ALLOYS TESTED.

Composition	Temper % Reduction	Tensile Strength Tons per Sq. In.	Elongation % on 2-in.	Stress for a Life of 1,000,000 Cycles Tons. per Sq. In.	Stress for a Life of 100,000, Cycles Tons. epr Sq. In.	Endurance Ratio
91·2% Cu, 8·8% Zn	84	36·25	4·0	15·75	11·5	0·32
	60	30·5	5·5	14·5	10·5	0·35
62·62% Cu, 37·38% Zn	84	59·0	3·0	18·25	11·0	0·19
	60	42·5	5·5	17·5	19·5	0·20
95·41% Cu, 4·37%Sn, 0·3% P	84	60·5	5·0	22·5	15·0	0·25
71·39% Cu, 0·92% Sn, 27·67% Zn	84	66·5	1·5	20·5	13·25	0·20
	60	53·25	3·0	19·5	11·25	0·21
96·22% Co, 2·82% Si, 0·95% Zn	80	66·75	4·0	21·25	14·75	0·22
	60	55·5	5·5	20·0	14·25	0·26
79·53% Cu, 20·2% Ni, 0·46% Mn	88	34·75	4·5	20·5	17·0	0·40
75·82% Cu, 23·38% Ni, 0·48% Mn	88	42·15	5·0	22·25	19·5	0·42
70·24% Cu, 29·11% Ni, 0·50% Mn	88	46·5	4·0	22·25	17·5	0·36
97·94% Cu, 1·10% Ni, 0·75% Sn, 0·22% P	94	62·0	2·5	22·25	19·25	0·31

Proc. American Society for Testing Materials, 1945, Vol. 43, pp. 774–783.

Water Jet Quench Improves Aluminium

USE of the water jet quench in the heat-treatment of aluminium alloys has been adopted in the St. Louis plant of Curtiss-Wright as the most efficient method of preventing distortion during the operation, and at the same time obtaining a quench rapid enough to prevent inter granular corrosion. The jet quench equipment consists of a housing 5 ft. wide, 14 ft. long and 6 ft. high (1·50, 4·25 and 1·85m.)—large enough to accommodate the capacity of the furnace it serves—and an interior studding of some 240 jets, or nozzles, around the sides, ceiling and bottom of the housing. Accompanying water tanks, pumps and electrically-operated conveyer tables for moving the materials from the furnace to the quench housing complete the assembly. Water is ejected through the nozzles at the rate of 2,000 gal. (75 hl.) in 30 sec., under pressures ranging from 35 to 60 psi. (2·5 to 4·2 kg./cm.²). Through this quenching method the surface of the metal is not blanketed in steam, as in dip quenching, and the part is cooled uniformly over its entire surface. It is superior to "fog" quenching in that the nozzles, or jets, have sufficient

From *Aero Digest*, March 1, 1945.

volume and pressure to break up any steam blanket generated by water-vapour contacting metal surfaces. This large quantity of water also insures a sufficiently rapid quench so that intergranular corrosion is not a problem.

Water from the jets, after quenching the metal, drops into an open tank below and is pumped back into the supply tank above the housing. The temperature of the water is measured periodically. When it approaches 100° F. (38° C.) fresh water is supplied. The housing is placed within one ft. (30 cm.) of the furnace so that there is a minimum of time lost in the operation, tending toward more uniform results in the treatment. The entire operating cycle is controlled automatically from an electrical control panel where a controller keeps the heat of the furnace at approximately 920° F. (490° C.) during the 20-min. soaking period. There is some variation in the temperature and the time of heating, depending on alloy thickness, etc.

Three furnaces and quench housings of varying sizes are in use in the plant. These have been tested thoroughly to to insure strict compliance with specifications for treatment of metal for corrosion resistance as well as tensile and yield strengths. Numerous tests on various types of aluminium alloys have been made with the jet quench method and it has been found more satisfactory than any other so far used to maintain straightness during heat treatment with a minimum of line-up expense.

Some Recent Developments in Materials

By A. Black

Calcium.—Calcium metal is used as a deoxidizer and cleanser in the manufacture of the highest-quality steels which must pass rigid cleanliness specifications, and to improve the hot-working characteristics of a number of the high-alloy steels. It is used as a reducing agent in the preparation of pure metals such as beryllium, titanium and zirconium. In the magnesium and aluminium industries it is used variously as an alloying agent, to simplify casting operations and to speed up heat-treating cycles. It also has proved valuable as a hardener in lead alloys used for bearing metals and cable sheaths. Still other uses are for the debismuthing of lead, and in some copper-aluminium alloys it is used in fractional percentages to prevent hot-shortness. Its effect as a hardener in lead is most pronounced and it increases the fatigue life of lead remarkably.

Indium.—The development of this metal is so recent and the price is still so high that its possibilities have not yet been fully explored. One of the first uses was in dental casting alloys where small percentages were found to improve corrosion resistance, hardness and strength. Another application was found in the use of fractional percentages to improve wear resistance and corrosion resistance of copper-lead and cadmium-lead bearing metals. The most recent application is the rather unique plating process used for extending the life of bearings. This is already used extensively in aviation engines and is applied as follows: The bearing shell is plated with a layer of silver, upon which is plated a layer of lead. A thin layer of indium is then plated on the lead, after which the part is moderately heated. The heating causes the indium to become diffused into the lead, uniting with it to form a hard alloy surface which greatly increases the bearing life. The pure metal is very soft, has a very low melting point and is highly corrosion-resistant. It is a fair conductor of electricity, about 20% that of copper, and has an exceptionally high coefficient of thermal expansion, being about twice that of copper.

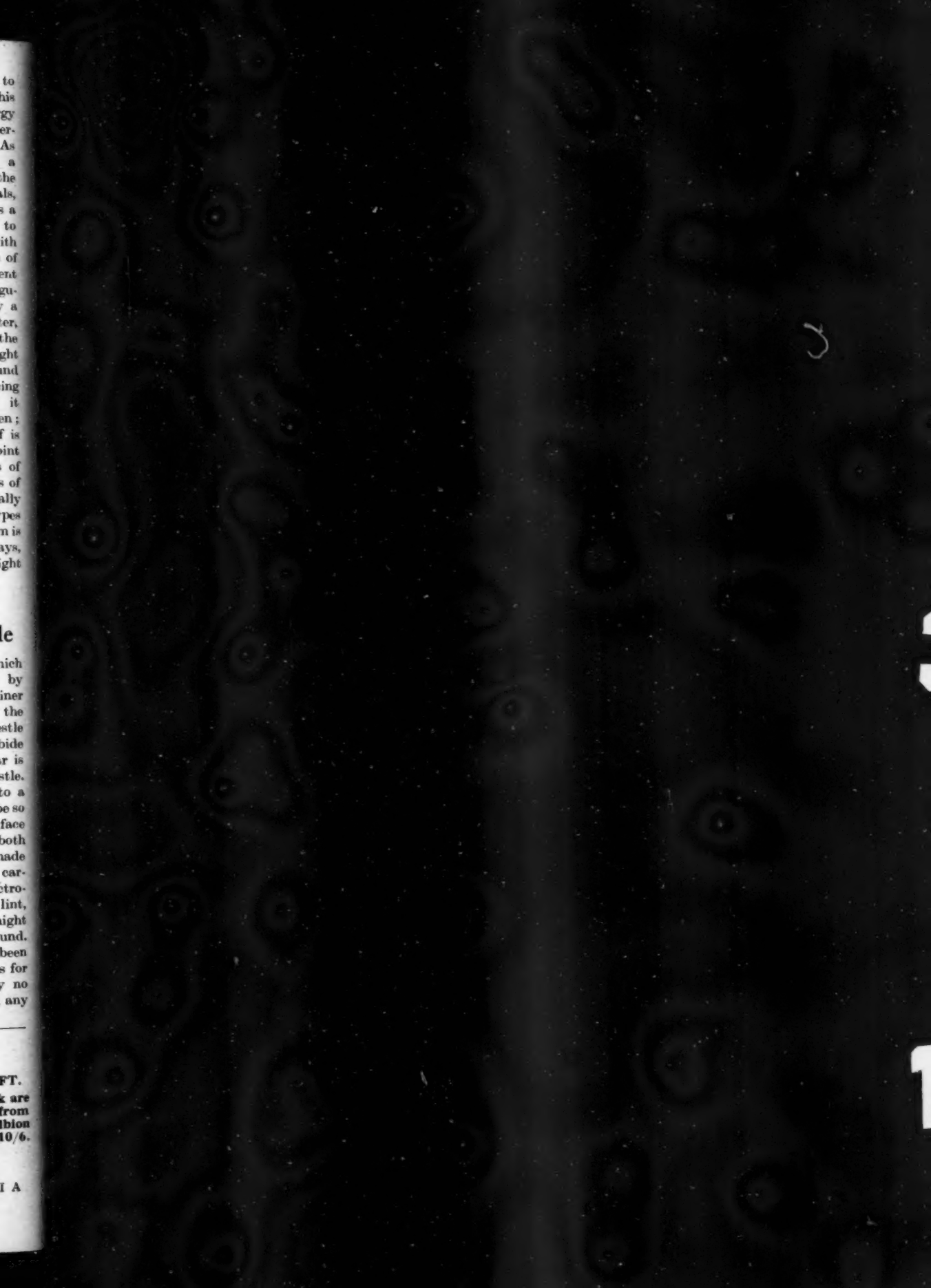
Lithium.—Current chief use of metallic lithium is in master alloys (introduced within the past 10 years) and in compounds made from the metal. These master alloys are used in metallurgy because of the exceptionally high affinity of lithium for gases and non-metallic impurities. Master alloys are now available of lithium in combination with one or more of the following metals: aluminium, copper, lead, magnesium, manganese, nickel, silicon, tin and zinc. Commercial lithium ranges from 98 to 99% pure. Another application advocated for lithium is in heat-treating, where it can be used in the furnace to produce a nonoxidising atmosphere. One of the outstanding characteristics of metallic lithium is its readiness to combine with other elements; this quality makes it useful in metallurgy but renders it unsuitable for engineering applications in the pure state. As an alloying element, lithium has a tendency to harden and strengthen the matrix in low-melting point metals, especially aluminium and lead. As a result of its pronounced tendency to form intermetallic compounds with many other metals, high additions of lithium often result in embrittlement of the alloy. Thus despite the intriguing fact that lithium weighs only a little more than half as much as water, it does not offer promise as the base metal of an ultra-lightweight alloy. However, it has been found exceptionally valuable in producing high-conductivity copper where it removes both oxygen and hydrogen; only a trace of the lithium itself is left in the copper. From the viewpoint of the design engineer, lithium is of chief interest as providing a means of eliminating most of the defects usually encountered in castings of many types of metal. Another feature of lithium is its exceptional transparency to X-rays, which pass through it like visible light through glass.

From *Mechanical Engineering*, March, 1945.

Hard Mortar and Pestle

BORON carbide, the material which is excelled in hardness only by natural diamonds, provides the liner and working tip, respectively, of the new laboratory mortar and pestle developed by the New England Carbide Tool Co. The body of the mortar is steel, as is the handle of the pestle. Both liner and tip are polished to a mirror finish. Surfaces are said to be so smooth that pit marks or surface irregularities are eliminated, and both the mortar and the pestle can be made sterile clean after use. Since the carbide does not build up or hold electrostatic charges, it will not pick up lint, dust or metal particles which might contaminate materials being ground. These mortars and pestles have been used in large scientific laboratories for over six months with absolutely no signs of wear or contamination in any experiments.

Business Week, February 17, 1945.

STEELS IN ENEMY AIRCRAFT.

SOME copies of the above book are still available. Order direct from the Kennedy Press, Ltd., 21, Albion Street, Manchester, 1, enclosing 10/6.